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Geology and Ground-Water Flow in the Potoniac-Raritan-Magothy Aquifer System Logan Township, New Jersey.

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in the
Potomac-Raritan-Magothy Aquifer System
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by
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Professor in Charge

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1.0 ABSTRACT

Logan Township, Gloucester County, New Jersey, contains several sites where ground-water contamination problems have developed. Logan Township is located within the outcrop area of the Potomac-Raritan-Magothy aquifer system, which in this area consists of unconsolidated Cretaceous and Quaternary age sediments. Palynological, heavy mineral, and well log analyses show that inter- and intraformational erosion have created complex hydrogeologic conditions.

Three major aquifers are in the southeastward dipping fluvial, channel deposits of the Potomac Group, and Raritan and Magothy Formations. Quaternary deposits add a degree of heterogeneity to the upper one to thirty meters of the aquifer system. Aquitards between the aquifers are discontinuous on a local scale due to inter- and intraformational erosion.

A complex ground water flow system with local, intermediate, and regional components, exists in the study area. The complexity is the result of: a heterogeneous, anisotropic aquifer; surface water-ground water interactions; climatic variations; and pumping wells. Evidence of this complexity consists of variable flow directions both within and between different levels (i.e., water table, shallow artesian) of the aquifer.

Logan Township is located in a regional recharge area. Based on the geologic framework of the aquifer and water level data, a significant portion of recharge flows downdip and/or vertically

downward, and is lost to the regional flow system. Estimates based on regional water level and numerical model studies suggest that up to 40 percent of available precipitation is lost to the regional flow system.

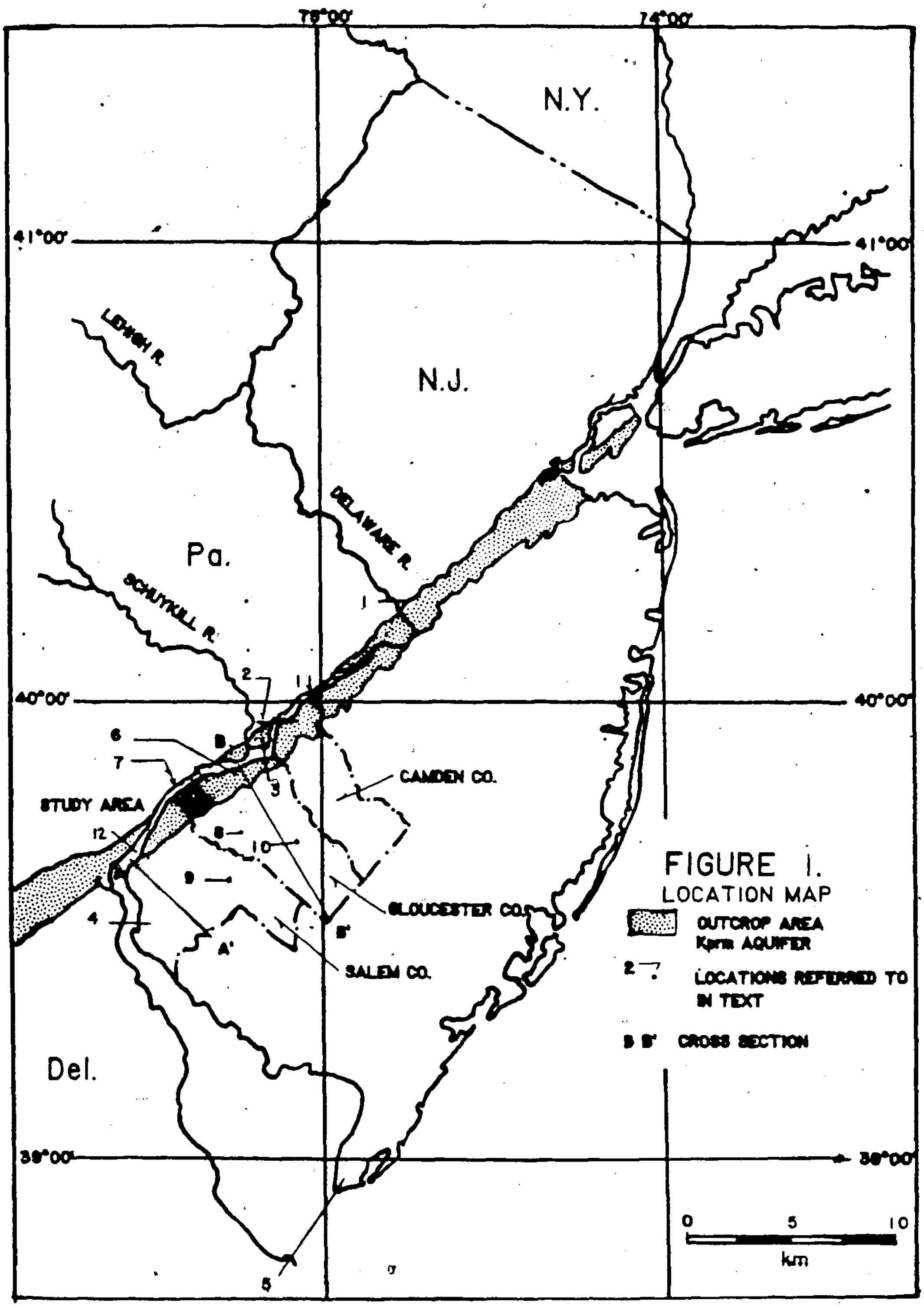
All information indicates that contaminants introduced at the surface can, where subsurface conditions permit, migrate downdip and/or vertically downward to deeper portions of the aquifer, and become incorporated with the regional flow system. The vertical flow component is partly dependent on climatic conditions. Additionally, the vertical flow component is enhanced by pumping wells and on land disposal of waste fluids. Due to the heavy use of this aquifer, the fate of the contaminants will be of long term concern.

2.0 INTRODUCTION AND PREVIOUS WORK

The Potomac-Raritan-Magothy Aquifer System is the main source of potable water in the lower Delaware River Valley, New Jersey (Luzier, 1980). The aquifer crops out along a narrow band parallel and adjacent to the river (Figure 1). The combination of proximity to major transportation routes and the abundance of good quality water has attracted numerous petrochemical plants and related industries to the area. As a result of this industrialization, ground-water contamination has become a problem. Logan Township, Gloucester County contains several sites where ground-water contamination problems have developed. The long term impact of contamination in this area is uncertain because ground water flow paths are not well known.

The study area is located within the Coastal Plain Physiographic Province in Logan Township, Gloucester County, New Jersey (see Figure 1). The Coastal Plain is underlain by a southeastward thickening wedge of unconsolidated Cretaceous, Tertiary, and Quaternary age sediments (Figure 2). Beneath the Coastal Plain section is the Wissahickon Group (crystalline basement). The surface of the Wissahickon Group slopes to the Southeast.

The study area is underlain by approximately 45-150 meters (m) of Coastal Plain sediments, which in this region consist of the Quaternary Cape May Formation, alluvium, and marsh sediments that disconformably overlie the Cretaceous units of the Potomac


75°00'
74°00'
N.Y.
41°00'
41°00'
LEHIGH R.
N.J.
DELAWARE R.
Pa.
SCHUYLKILL R.
1
2
11
40°00'
40°00'
6
B
7
3
CAMDEN CO.
STUDY AREA
12
8
10
9
GLOUCESTER CO.
4
B'
A'
SALEM CO.
FIGURE 1.
LOCATION MAP
OUTCROP AREA
Kprm AQUIFER
LOCATIONS REFERRED TO IN TEXT
B B' CROSS SECTION
Del.
39°00'
39°00'
0
5
10
km
5

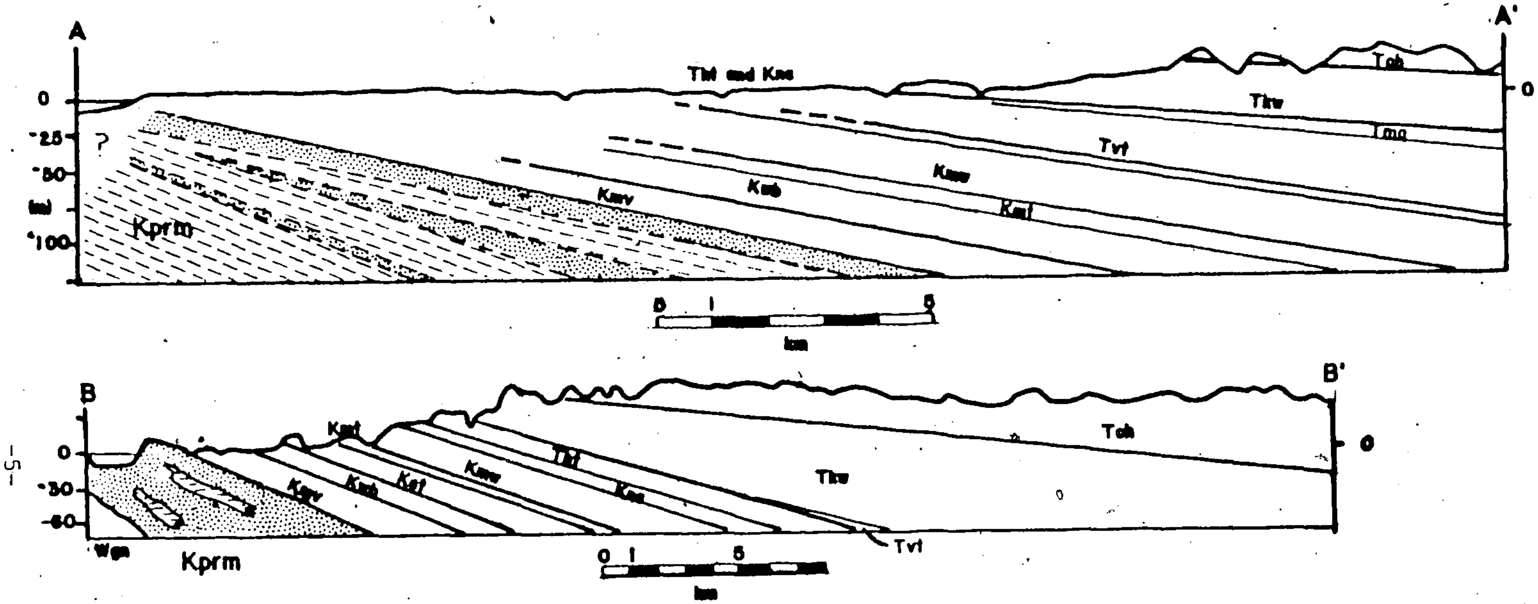


FIGURE 2. REGIONAL CROSS SECTIONS.

A-A' From Rosenau et al. 1969

B-B' From Hardt and Hilton 1969

SAND

CLAY

K-CRETACEOUS
Kprm-Potomac-Raritan-Magothy Aquifer System
Kmv-Merchantville Formation
Kwb-Woodbury Clay
Ket-Englishtown Formation
Kmt-Marshalltown Formation
Kmw-Mount Laurel and Wenonah Formations
Kns-Navesink Formation

T-TERTIARY
Tht-Hornerstown Formation
Tvt-Vincentown Formation
Tmq-Manasquan Formation
Tkw-Kirkwood Formation
Tch-Cohansey Formation

Wgn-Wissahickon Formation (Precambrian)

Group, Raritan, and Magothy Formations. In general, it is impossible to distinguish the Cretaceous Potomac Group and Magothy Formation from the Quaternary units on the basis of gross lithology. As a result, many hydrogeologic investigations have considered the Potomac Group and the Magothy and Cape May Formations as a single operational unit (Rosenau et al., 1969; Hardt and Hilton, 1969; Farlekas et al., 1976). In the study area; ground-water flow is affected by the subsurface distribution and hydrogeologic character of both the Cretaceous and Quaternary units. Therefore, a detailed understanding of subsurface geologic conditions is crucial to the interpretation of ground-water flow.

The purpose of this study is to synthesize detailed subsurface geology and available hydrogeologic data into reasonable models of the local hydrogeologic regime; and, to help interpret and predict flow paths with the use of ground water flow models.

2.1 GEOLOGY

2.1.1 Structural Setting

The study area is located on the southern edge of the South New Jersey uplift (Owens and Sohl, 1969). The basement structure has episodically been active since at least the late early Cretaceous. Structural activity has caused differential movements between the northern and southern portions of the New Jersey Coastal Plain which has shifted the location of Coastal Plain depocenters (Minard, 1974;

1980). Basement structures may also have had some influence on the course of the lower Delaware River, and therefore the erosional history of the area (Higgens et al., 1974; Owens and Sohl, 1969). Additional comments on the role of these shifting depocenters is presented below.

2.1.2 Stratigraphy

The stratigraphy of the Cretaceous and Quaternary deposits has been the subject of considerable debate over the years. However, studies completed within the last 10 to 15 years have clarified the stratigraphy of the Cretaceous section. The stratigraphy of the Quaternary section is still somewhat problematic. A compilation of several recent published stratigraphic interpretations is shown in Tables 1a and 1b.

a. Potomac Group and Raritan Formation

The Potomac Group is the basal Coastal Plain unit in southern New Jersey, Delaware, Maryland, and Virginia (Minard, 1980). It has been subdivided into the Patuxent, Arundel, and Patapsco-'Raritan' units (Glaser, 1969). These units can not always be differentiated on the basis of gross lithology. For this reason, Glaser (1969) has considered this sequence as the undifferentiated Potomac Group. The Potomac Group has been subdivided (see Table 1a) on the basis of microflora (pollen) (Minard, 1980). However, the results of several biostratigraphic studies indicate that the 'Raritan' of Maryland, Delaware, and southern New Jersey is probably younger than the

TABLE 1A.
CRETACEOUS STRATIGRAPHIC CORRELATIONS

		NJ	DEL.	MD.
CRETACEOUS	UPPER	MAGOTHY FRM.	MAGOTHY FRM.	MAGOTHY FRM.
CRETACEOUS	LOWER	RARITAN FRM. / POTOMAC GRP.	POTOMAC GRP.	POTOMAC GRP.

FROM MINARD (1980)

AGE		WOLFE AND PAKISER (1971) FORMATION	DOYLE (1977) ZONE		DOYLE (1977) FORMATION
UPPER	TURONIAN				RARITAN (NJ)
UPPER	CENOMANIAN	RARITAN (NJ)	IV		RARITAN (NJ)
UPPER	CENOMANIAN	'RARITAN'	III		'RARITAN'
LOWER	ALBIAN	ARUNDEL	II	C	PATAPSCO
				B	PATAPSCO
				A	PATAPSCO
LOWER	APTIAN	PATUXENT	I		ARUNDEL
LOWER	BARREMIAN		I		PATUXENT
			?		?
LOWER	NEOCOMIAN				

TABLE 1B.
QUATERNARY STRATIGRAPHIC CORRELATIONS

AGE		JOHNSON (1952)
QUATERNARY	HOLOCENE	UNNAMED MARSH, SWAMP, RIVER-FILL, AND ALLUVIAL DEPOSITS
QUATERNARY	PLEISTOCENE	CAPE MAY FRM.
		PENNSAUKEN FRM.
		BRIDGETON FRM.

AGE		NEW JERSEY	DELAWARE MARYLAND
		FROM OWENS ET AL (1983)	
QUATERNARY	HOLOCENE	UNNAMED MARSH, SWAMP, RIVER-FILL, AND ALLUVIAL DEPOSITS	
QUATERNARY	PLEISTOCENE		SINEPUXENT FRM. PARSONBURG SAND
QUATERNARY	PLEISTOCENE	VAN SCIVER LAKE BEDS SPRING LAKE BEDS	IRONSHIRE FRM. OMAR FRM.
TERTIARY	MIOCENE	PENNSAUKEN FORMATION BRIDGETON FORMATION	POCOMOKE-MANOKIN BEDS

Patapsco and older than the type section Raritan of central New Jersey (Minard, 1980).

The Salisbury and Raritan embayments, located roughly beneath Maryland and East Central New Jersey respectively, were the major depocenters for the Potomac Group and Raritan and Magothy Formations respectively. Doyle (1977) and Wolfe and Pakiser (1971) suggest that, in the outcrop area, the older Potomac Group units are thickest in the Salisbury embayment and thin towards the Northeast, wedging out near Trenton. Conversely, the younger Raritan Formation is thickest in the Raritan embayment and thins to the Southwest. Farlekas et al. (1976) report that palynologic data indicates that both Patapsco and Raritan age sediments are present in Camden County. The wedge geometry is thought to be due to differential subsidence which caused the Potomac Group depocenter to move northward during the Cretaceous Period (Doyle, 1977).

b. Magothy Formation

The Magothy Formation unconformably overlies the Potomac Group and Raritan Formation (Minard, 1980). Palynologic studies by Sirkin (1974) and Wolfe and Pakiser (1971) indicate that there was a significant hiatus between the end of Potomac and Raritan deposition and the beginning of Magothy depostion. In southern New Jersey, the Magothy Formation and the undifferentiated Potomac Group have traditionally been considered as a single operational unit because of mapping difficulties created by similar lithologies and lack of exposures (Johnson, 1952; Hardt and Hilton, 1969).

The base of the Potomac Group and the top of the Magothy Formation dip to the Southeast at approximately 0.011 m/m and 0.0085 m/m respectively (Hardt and Hilton, 1969).

c. Quaternary Section

A compilation of several stratigraphic interpretations is shown in Table 1b. (There are marked differences in the ages of some units as assigned by different investigators. The absolute ages of the units are not an issue in this study.) The Cape May Formation has been considered by several studies to be of Sangamon age (Owens and Minard, 1979). Owens and Minard (1979) divide the Cape May Formation into the Spring Lake and Van Sciver Lake beds based upon surface elevations, scattered exposures of the unconformable contact, and correlations with similar age units in Delaware. The generalized geologic maps and cross sections contained in Owens and Minard (1979) and Owens et al. (1983) indicate that, in the lower Delaware River Valley, the Spring Lake and Van Sciver Lake beds correspond to the Cape May Formation of Salisbury and Knapp (1909) and Johnson (1952). Further downvalley, in Cape May County, Owens and Minard (1979) correlate the Van Sciver Lake beds with the Cape May Formation of Gill (1962).

Although upper Wisconsinan age units (Parsonburg Sand and Sinepuxent Formation) have been mapped on the Delmarva Penninsula, they have not been mapped in southern New Jersey (Denny et al., 1979; Owens and Denny, 1979). However, Johnson (1937) and Owens et al. (1974) have identified Wisconsinan age deposits beneath the present Delaware River. Additionally, Salisbury and Knapp (1909) have mapped post-Cape May wind blown sand deposits in southern New Jersey which may be correlative with the Parsonburg Sand.

2.1.3 Depositional Models

a. Potomac Group and Raritan Formation

There is general agreement on the depositional environment of the Potomac Group. Minard (1980) states, 'the sediments of the Potomac Group were probably deposited by a complex river system of channels, floodplains, and cutoff meander swamps.' Deposition occurred during the worldwide early Cretaceous transgression (Petters, 1976). Force and Moncure (1978) and Groot (1955) conclude that the composition of the Potomac Group sediments indicates that they were probably derived by intense acid weathering of Piedmont crystalline rocks and deposited in a well drained basin.

Abrupt lateral and vertical lithologic changes and vertical persistence of channel sands (multi-story sand bodies) have been noted in the Potomac Group by Spoljaric (1967) and Farlekas et al. (1976). Multi-story sand bodies are usually formed by repeated migration of river channels within the same meander belt (Blatt et al., 1980). Farlekas et al. (1976) and Spoljaric (1967) also note that channel trends are located above troughs in the basement surface. Major Cretaceous drainage systems are apparently associated with the larger and deeper troughs (Farlekas et al., 1976). Locally, two of the larger troughs occur beneath the Schuykill and Christiana Rivers (Farlekas et al., 1976; Woodruff and Thompson, 1972).

b. Magothy Formation

Many authors have concluded that the Magothy Formation was deposited in continental to near shore marine environments. Glaser (1969) and Groot (1955) suggest that, during deposition of the Magothy Formation, the depositional environment evolved from fluvial to marine. Sundstrom et al. (1975) suggest that the pronounced trough-ridge system at the base of the Magothy Formation, running nearly perpendicular to the strike, is probably due to erosion during the depositional hiatus between the Potomac Group and Magothy Formation. Spoljaric (1972) suggests that facies changes along strike are likely.

c. Quaternary Section

Owens and Minard (1979) conclude that the Spring Lake and Van Sciver Lake beds were deposited in distinct regressive-transgressive episodes. Data on the vertical limits of the regressive-transgressive episodes are presented in Table 2.

Table 2
Vertical extent of Quaternary Units

Unit	Location (numbers refer to Figure 1)	Basal Elevation m, Mean Sea Level (MSL)	Top Elevation m, MSL
Spring Lake Beds	1. Trenton, NJ	-2	15
	2. Ben Franklin Br.	-8	20
	3. Red Bank, NJ	-16	14
	4. Artificial Is., NJ	-1	12
Van Sciver Lake Beds	Trenton, NJ	-3	6
	Ben Franklin Br.	<-15	8
	Red Bank, NJ	-16	6
	Artificial Is., NJ	-23	3
	5. Cape May, NJ	-61	7
Late Wisconsinan	Ben Franklin Br.	-19	
	Red Bank, NJ	-27	
	6. Paulsboro, NJ	-27	
	Artificial Is, NJ	-45	
	Cape May, NJ	-58	

Sources: Figures 27-30 from Owens and Minard (1979), Johnson (1937)

A pattern of downvalley facies changes are associated with the Spring Lake and Van Sciver Lake beds. Owens and Minard (1979) liken these facies changes to the downvalley change from fluvial to estuarine conditions existing in the modern Delaware River. Similar downvalley facies changes are noted in the tributary valleys (Owens and Minard, 1975). Salisbury and Knapp (1917) suggest that in the Bridgeport area, the Cape May Formation may have been deposited as estuarine fill.

The geology of the Bridgeport area was modified, after deposition of the Cape May Formation, by both fluvial and eolian processes. A mid-Wisconsinan high sea level stand has been suggested by Belknap and Kraft (1976) and Owens and Denny (1978). Owens and Denny (1978) postulate that the Sinepuxent Formation was deposited as fill in an estuarine environment during this time period.

During the low sea level stands of the glacial maxima, the ancestral Delaware incised deeply into underlying units (Owens et al., 1974; Johnson, 1937). Johnson (1937) indicates that the ancestral Delaware River cut to nearly -30.5 m MSL near Paulsboro. Data from numerous river bottom borings and seismic data from Moody and Von Reenan (1967) suggests that the depth of erosion was partly controlled by the presence of bedrock.

The upper Wisconsinan paleoclimate of the southern New Jersey, Delmarva Peninsula area has been studied by Sirken et al. (1974). On the basis of palynological data, they conclude that the climate was cooler and drier than the present climate. The Parsonburg Sand, which was deposited during this period (Owens and Denny, 1979), is largely an eolian deposit derived from the local Coastal Plain units (Denny, 1979). The eolian deposits which Salisbury and Knapp (1909; 1917) recognized in the study area may be correlatives of the Parsonburg.

Recent sea level history has been studied by Kraft (1969; 1971) and Belknap and Kraft (1976). They found that local basement subsidence and sediment compaction have complicated regional interpretations of sea level changes. Demarest et al. (1981) found that the sea level variations created complex erosional and depositional features in the estuaries and coastal streams of the

Delmarva Peninsula. Kraft (1969; 1971) noted that Holocene drainage is superimposed on the older Pleistocene drainage systems. This undoubtedly has also been the case in the study area.

In summary, the combination of cross-cutting relationships, multiple regressive-transgressive cycles, post-depositional modification, and downvalley facies changes has created an extremely complex erosional and depositional history within the study area.

2.1.4 Regional Geology and Sediment Provenance

Figure 3 shows the distribution of rock types expected to have contributed sediment to the Coastal Plain units. Based on geographic proximity, heavy mineral suites, and gross lithology, it is clear that the metamorphic and igneous rocks of the Piedmont have contributed the largest percentage of sediments to the Cretaceous units. Owens and Minard (1975) have found that the compositions of most Quaternary deposits reflect the rock types found upvalley in the present drainage systems. As a result, the Quaternary deposits in many cases are virtually indistinguishable from the underlying Coastal Plain units from which they were derived.

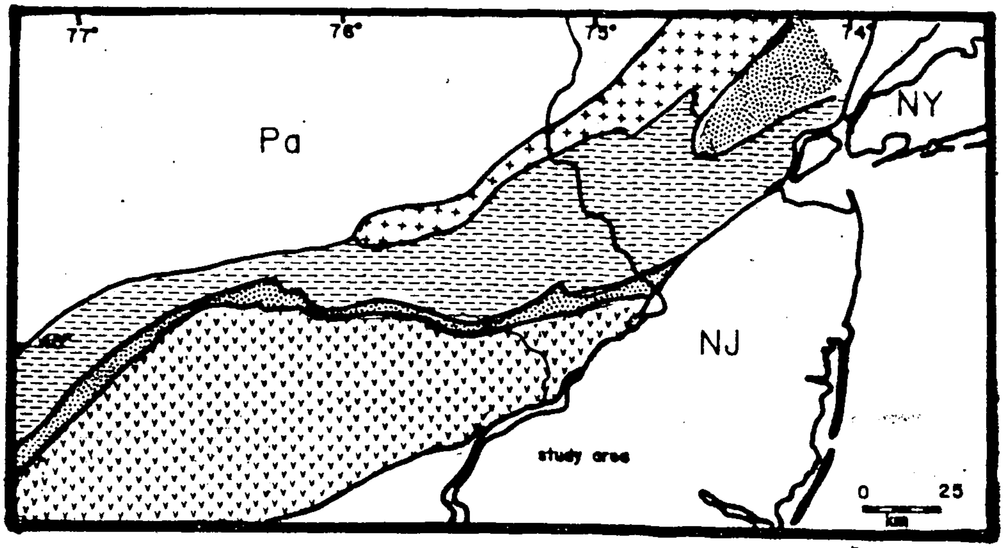


FIGURE 3. SOURCE ROCK LITHOLOGY.

FROM OWENS AND MINARD (1979).

- Triassic arkosic sands and gravel, some diabase
- Triassic red shale and sandstone, some diabase
- Coastal Plain Rocks
- New Jersey Highland gneiss and schist, abundant intrusive rocks
- Piedmont metamorphic and igneous rocks

2.1.5 Lithology and Mineralogy

a. Potomac Group, Raritan and Magothy Formations

In the outcrop area, the Potomac Group is characterized by large and abrupt lateral and vertical variations in lithology (Glaser, 1969; Hardt and Hilton, 1969). In general, it is composed of variable combinations of gravel, sand, silt, and clay. The sand units of the Potomac Group, Raritan and Magothy Formations are usually proto- or orthoquartzites (Groot, 1955; Glaser, 1969; Owens and Sohl, 1969). The typical Potomac clays are variegated or mottled red, gray, white, and yellow; whereas, in general, the typical Magothy clays are darker and contain more organic matter, concretions, and pyrite. As compared to those of the Potomac Group, the sand and clay units of the Magothy Formation tend to be relatively homogeneous bodies which are laterally traceable for hundreds of meters (Glaser, 1969; Minard, 1974).

Distinct heavy mineral zones in the Potomac Group and the Raritan and Magothy Formations have been identified by Groot (1955) and Glaser (1969) within the Salisbury embayment. These zones appear to correlate with paleontologic divisions of the Potomac Group and Magothy Formation. Similar heavy mineral zones exist in Central New Jersey, where McCallum (1957) found typical Patapsco or Raritan suites in samples taken from the outcrop area of the Raritan Formation. The characteristic assemblages of each unit are shown in Table 3.

The heavy mineral compositions of the Potomac Group, Raritan and Magothy Formations in southern New Jersey have not been as extensively studied. Reconnaissance work by Groot (1955) found an apparent correlation between the Potomac Group or Raritan Formation of Southern New Jersey and the Patapsco-Raritan section in the Salisbury embayment. Based on unpublished results, Owens and Sohl (1969) reported similar suites for the Raritan and Magothy Formations and concluded that heavy minerals can not be used to distinguish between the Cretaceous units in southern New Jersey.

Table 3
Non Opaque Heavy Mineral Suites
of the Cretaceous Units

Unit	Heavy Mineral Suite
Patuxent (1,2)	Staurolite, zircon
Patapsco (1,2)	Zircon, tourmaline, rutile
Raritan (3)	Zircon, tourmaline, rutile
Magothy (1,2)	Staurolite, tourmaline

(Sources: (1) Groot, 1955; (2) Glaser, 1969; (3) McCallum, 1957)

Descriptions and evaluations of the importance of the heavy mineral suites of the Coastal Plain source rocks have been compiled by Dryden and Dryden (1964).

b. Quaternary Units

Locally, the composition of the Quaternary units depends on the depositional environment and the relative importance of the Piedmont and Coastal Plain sediment provenances. Recent information indicates that the composition of these units is more variable than had been previously thought. In Gloucester and Salem Counties, Hardt and Hilton (1969) and Rosenau et al. (1969) describe the Cape May Formation (Spring Lake and Van Sciver Lake beds) as poorly sorted, subangular, medium to coarse quartzose sand with much gravel and minor amounts of clay. The sand and gravel are commonly yellow or brown, with minor gray units. The clays are yellow, brown, gray, and black. Owens and Minard (1979) describe the Van Sciver Lake beds, in an excavation at Artificial Island (location 4), as mostly interbedded dark gray to black, organic rich, clay-silt and medium to fine, green to reddish brown quartzose sands, silty sands, and sandy gravels. In general, the coarse grained beds are found in the basal and upper sections; while the fine grained beds are found in the middle of the sequence. This is similar to the section in Cape May County described by Gill (1962). In general, the Spring Lake beds are lithologically and mineralogically similar to the Van Sciver Lake beds (Owens and Minard, 1979).

The mineralogy and lithology of the upper Wisconsinan and Recent units have been studied by Groot (1955) and Kraft (1969). They found that the compositions of these units usually reflect the compositions of adjacent units. Organic-rich deposits comprise a large percentage of the bay-and river-fringing fill material (Kraft,1969; Belknap and Kraft, 1976).

The heavy mineral compositions of the Quaternary units are not as well known as those of the Cretaceous units. However, the heavy mineral suites of the Quaternary units are clearly quite different from those of the Cretaceous units. Gill (1962) and Owens and

Minard (1979) note a significant percentage of hornblende and other 'unstable' heavy minerals in the Cape May Formation (Spring Lake, Van Sciver Lake beds) but report no numerical results. Groot (1955) also reports significant concentrations of unstable minerals in samples taken from Quaternary units in Delaware. Owens et al. (1974) report significant concentrations of hornblende in upper Wisconsinan and recent sediments sampled from beneath the Delaware River near Camden (location 3).

2.1.6 Mapping and Subsurface Correlations

Detailed field mapping in the study area was last completed by Salisbury and Knapp in the early 1900's. A reproduction of part of the original map is shown in Figure 4. Reconnaissance mapping by the United States Geological Survey (USGS) (1967) and Owens and Minard (1979) provide the only recent remapping of the study area.

Since the Cretaceous units are largely covered, interpretations of the local stratigraphy and sedimentology are based on extrapolations from other areas and on well log correlations. As noted above, in southern New Jersey, where most subsurface investigations are initiated for hydrogeological purposes, the Cretaceous units have generally been considered as a single operational unit (Hardt and Hilton, 1969; Farlekas et al., 1976). Only the USGS (1967) has attempted to differentiate between the Magothy Formation and the underlying Potomac Group and Raritan Formation (Figure 5).

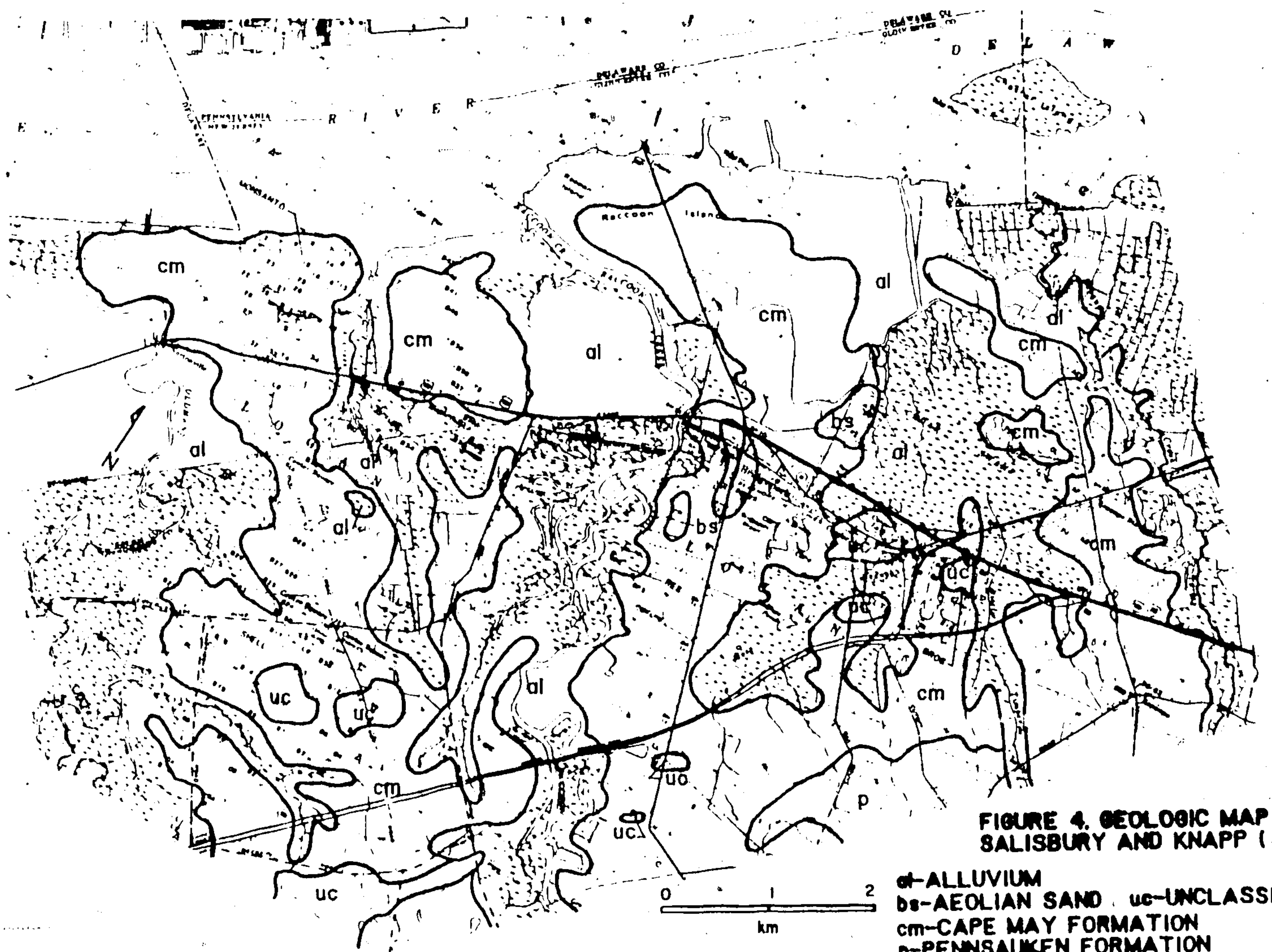


FIGURE 4. GEOLOGIC MAP OF SALISBURY AND KNAPP (1909).

al-ALLUVIUM
bs-AEOLIAN SAND uc-UNCLASSIFIED
cm-CAPE MAY FORMATION
p-PENNSAUKEN FORMATION

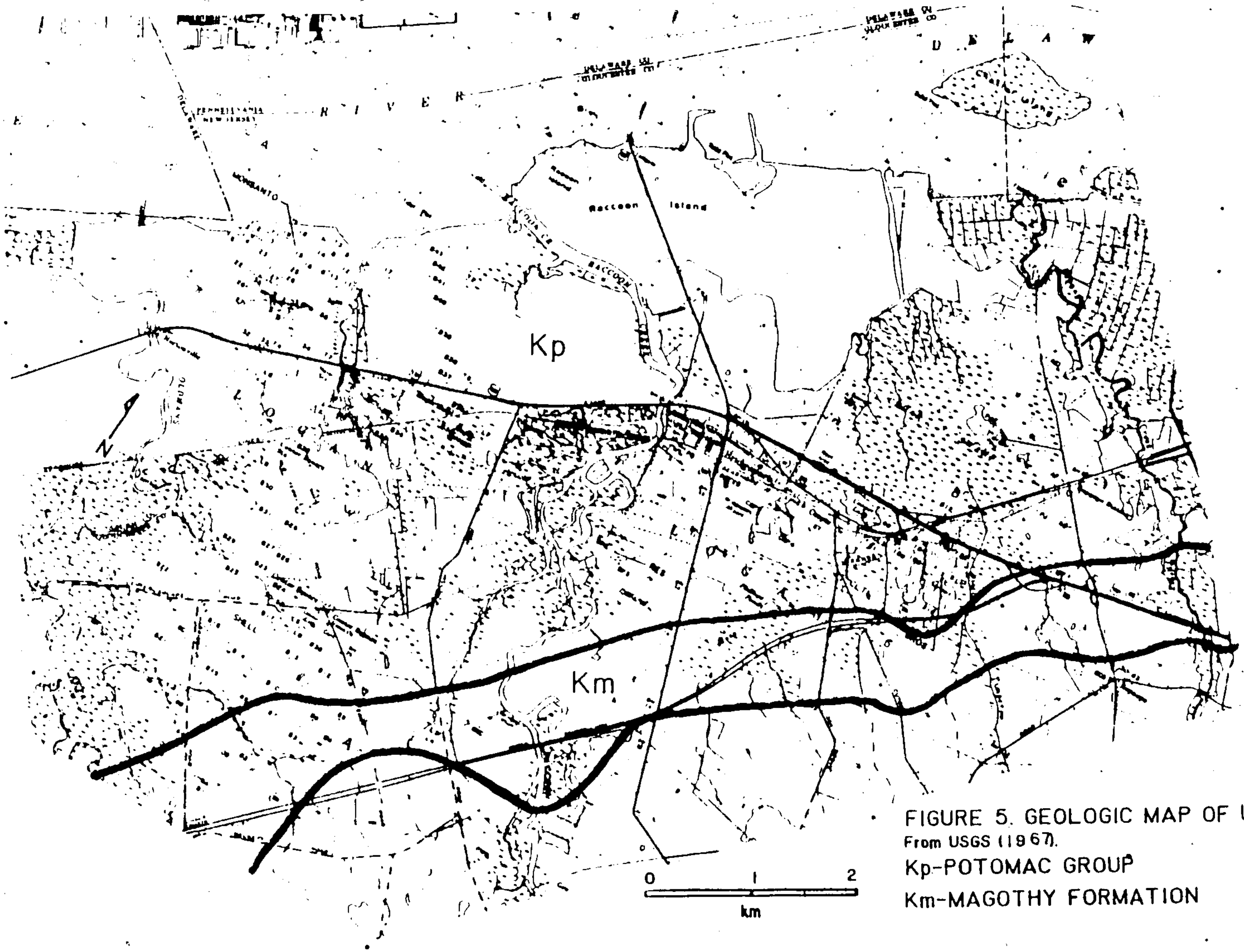


FIGURE 5. GEOLOGIC MAP OF USGS.
From USGS (1967).
Kp-POTOMAC GROUP
Km-MAGOTHY FORMATION

Interpretations in many privately funded ground-water pollution investigations are usually restricted to on-site well log correlations. Despite the emphasis placed on abrupt lateral and vertical lithologic changes in the literature, these reports commonly ascribe remarkable vertical and lateral continuity to the numerous thin clay layers of uncertain age found throughout the region (ERM, Inc., 1982; Geraghty and Miller, Inc., 1970).

2.2 HYDROGEOLOGY

2.2.1 Potomac-Raritan-Magothy Aquifer System

The Potomac Group along with the overlying Raritan and Magothy Formations make up the Potomac-Raritan-Magothy (Kprm) Aquifer System (Luzier, 1980). In the outcrop area, the aquifer may also include the overlying Cape May Formation (Farlekas et al., 1976). The most recent interpretations of the stratigraphy of the aquifer system are discussed by Walker (1983). It appears that water-bearing sands in the outcrop area of the southern part of the aquifer system function as two or three distinct hydrologic units. The lower and middle aquifers consist of beds of the Potomac Group and Raritan Formation (if present) and overlying Quaternary deposits. The upper aquifer consists of beds of the Magothy Formation and overlying Quaternary deposits. The upper aquifer is separated from the lower and/or middle aquifer by a sequence of silt and clay layers. Information on the age of this aquitard in southern New Jersey is lacking.

Also, the aquitard separating the lower and middle aquifers may pinch out in areas adjacent to the Delaware River.

Hardt and Hilton (1969) report that in the outcrop area, the upper aquifer includes the water-bearing beds of the upper 36 m of the Raritan and Magothy Formations. They also report that the lower aquifer includes the water-bearing beds of the lower 61 m of the formations.

2.2.2 Local Hydrogeologic Framework

Figure 6 (adapted from Geraghty and Miller, Inc., 1972) illustrates the general hydrogeologic framework of the study area. Three water bearing zones have been designated; a water table, shallow artesian, and deep artesian zone. Locally, the deep artesian zone (lower aquifer) contains brackish water and is not used (Geraghty and Miller, Inc., 1972). Consequently, available information and future discussion focuses on the water table and shallow artesian zones (middle and upper aquifers).

In general, the water table zone is composed of sediments of Quaternary age and the shallow artesian zone is composed of sediments of Cretaceous age (New Jersey Division of Water Resources (DWR), 1981). Locally however, the age of the sediment making up a particular water bearing zone may be different. For example, the water table zone may extend down into Cretaceous sediments and/or Quaternary sediments may be entrenched in the shallow artesian zone (Geraghty and Miller, Inc., 1972).

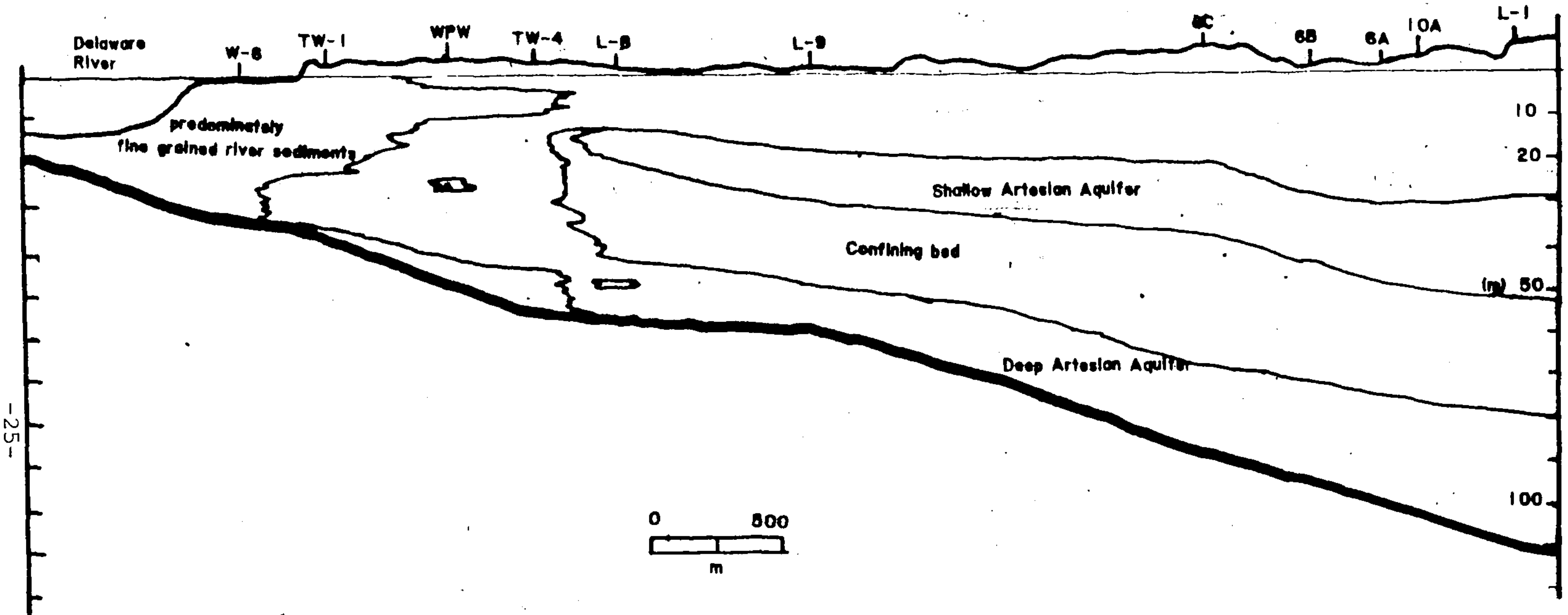


FIGURE 6. HYDROGEOLOGIC CROSS SECTION. From Geraghty and Miller 1972.

Based on pump test results, Geraghty and Miller (1972) conclude that, in general, the shallow artesian zone is best described as an infinite, isotropic, and leaky artesian aquifer without water released from storage in the confining beds. However, they note, that in reality, the shallow artesian zone does not have an infinite extent and is anisotropic. Pump tests have found the degree of interconnection between the water table and shallow artesian zones is spatially variable (Geraghty and Miller, Inc., 1972; 1981). Hardt and Hilton (1969) conclude that the upper and lower water bearing zones of the Kprm aquifer system are connected regionally, if not locally. The range of values of parameters for the aquifer and confining layers are summarized in Table 4.

2.2.3 Recharge and Regional Flow

a. Recharge

Before development, the Kprm was recharged solely by precipitation and discharged to the Delaware River and its tributaries (Vowinkel and Foster, 1981). However, within the past 50 years, ground water withdrawals have reversed the gradients in many areas; and, the aquifer now has the capability of inducing flow from, or reducing ground-water runoff to, the river (Vowinkel and Foster, 1981).

The average annual precipitation at the Marcus Hook weather station, located directly across the Delaware River from the study area, was 1.052 m per year for the period 1941-1978 (Vowinkel and Foster, 1981). Hardt and Hilton (1969) estimate that one-half of

Table 4
Hydrogeologic Parameters

SITE (see Figure 8)	WATER BEARING ZONE	TRANSMISSIVITY (m^2/sec)	COEFFICIENT OF STORAGE	(CONFINING) VERTICAL PERMEABILITY (m/sec)	REMARKS
Shell	shallow	1.68×10^{-3}	1.4×10^{-4}	1.41×10^{-4}	a.
	artesian	$- 9.20 \times 10^{-3}$	$- 2.9 \times 10^{-4}$	$- 4.72 \times 10^{-8}$	
Monsanto	shallow	2.88×10^{-3}	2.6×10^{-4}	2.00×10^{-9}	a.
	artesian	$- 1.15 \times 10^{-2}$	$- 7 \times 10^{-4}$		b.
Landtect	shallow	4.00×10^{-3}	----		c.
	artesian	$- 5.64 \times 10^{-3}$			
Rollins	shallow	2.30×10^{-3}	4.6×10^{-4}	3.20×10^{-8}	e.
	artesian	$- 1.29 \times 10^{-2}$			d.
Rollins	water table	6.32×10^{-4} $- 1.21 \times 10^{-3}$	----	----	e.

Table 4.
continued

SITE	WATER BEARING ZONE	TRANSMISSIVITY (m^2/sec)	COEFFICIENT OF STORAGE	(CONFINING) VERTICAL PERMEABILITY (m/sec)	REMARKS
CLTL	water table	2.60×10^{-4} - 1.14×10^{-3}	.07 (sy)	----	f.
Penns Grove #2	shallow artesian	4.97×10^{-3}	----	----	g.
Gloucester County (85 wells)		2.29×10^{-4} - 1.61×10^{-2}	9×10^{-5} - 1.74×10^{-4}	----	g.
Gloucester County average		4.89×10^{-3}	----	----	g.

Table 4.
continued

		HYDRAULIC CONDUCTIVITY (m/sec)			
BROS	water table	$3.05 \times 10^{-7} - 3.05 \times 10^{-5}$	----	----	h. lab test direct measurement
Shell Waterfront	----	$8.53 \times 10^{-11} - 1.00 \times 10^{-6}$	----	----	i. lab test on organic material

Sources: a. Geraghty and Miller, Inc. (1972), b. Geraghty and Miller, Inc. (1967), c. Geraghty and Miller, Inc., (1971), d. Geraghty and Miller, Inc. (1981b), e. DWR (1981), f. ERM (1982a), g. Hardt and Hilton (1969), h. Weston, Inc. (197), i. Woodward and Morehouse, Inc. (1972)

this is lost to evapotranspiration and the remaining half either discharges to streams (runoff) or to pumping wells. Geraghty and Miller, Inc. (1972) suggest that little if any of the available precipitation reaches streams as surface runoff. They estimate that approximately one-half of the total precipitation, or about one million gallons per day (gpd) per square mile, recharges the water table aquifer, but only a part of this reaches deeper parts of the aquifer.

b. Regional flow

The potentiometric surface of the lower aquifer is shown in Figure 7. Note that the study area is located in one of the few regions where the head is above MSL. In general, flow moves either towards pumping centers or downdip (Southeast) from the outcrop area. Near the Delaware River, this may be opposite to the flow direction of the surface drainage. Additionally, present flow directions are nearly opposite to the pre-development flow directions (northerly) suggested by Barksdale et al. (1958).

c. Local Flow

In general, ground-water flow in the water table zone is from topographically high areas toward adjacent bodies of surface water. Locally, these flow directions may be affected by tidal fluctuations (Hardt and Hilton, 1969). Data from Walker (1983) and Geraghty and Miller, Inc. (1972; 1982) indicate that water in the shallow artesian zone may flow either toward the Monsanto pumping center, or downdip through the units, depending on the position of the flow lines within the aquifer (see Figure 7).

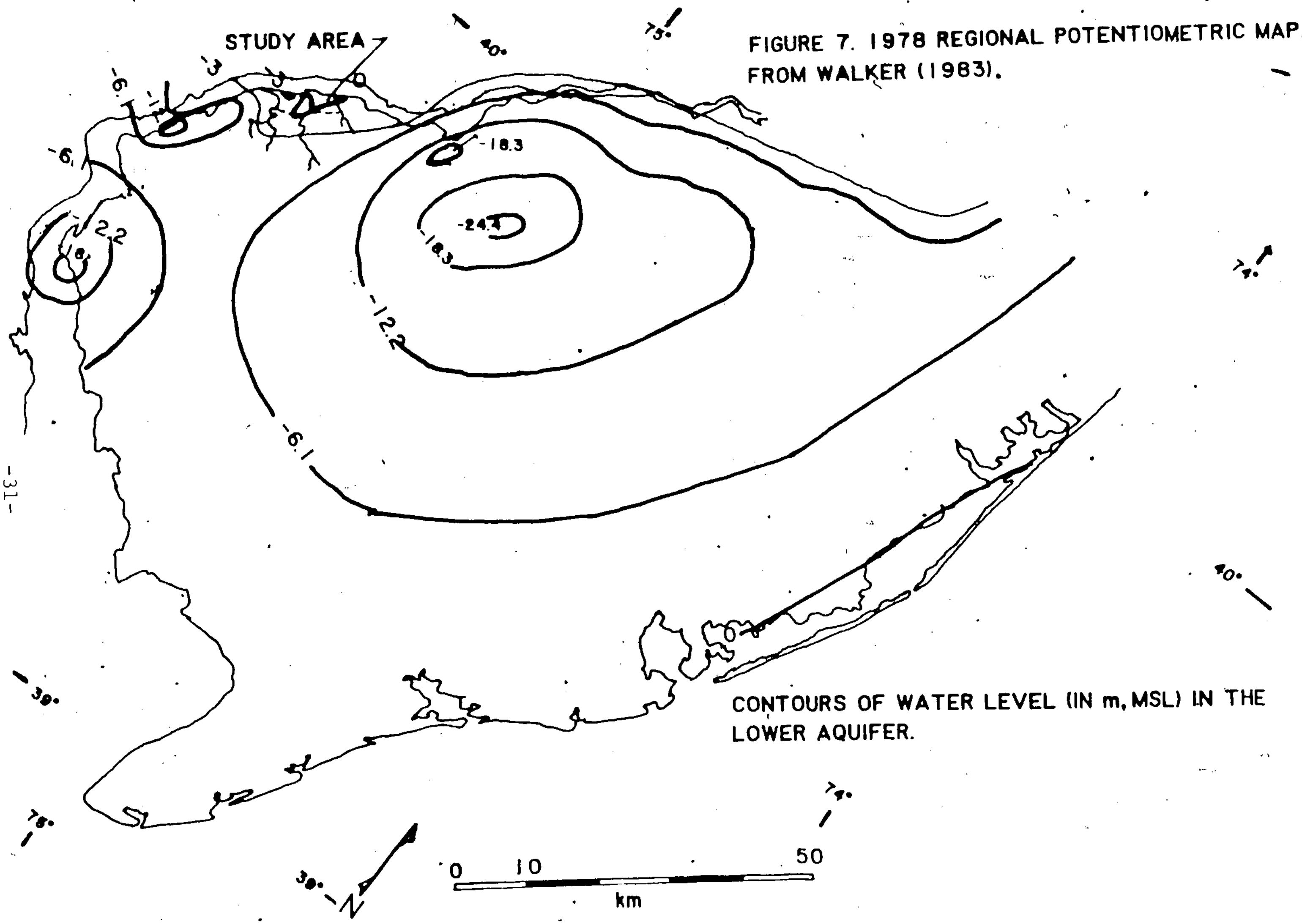


FIGURE 7. 1978 REGIONAL POTENTIOMETRIC MAP. FROM WALKER (1983).

CONTOURS OF WATER LEVEL (IN m, MSL) IN THE LOWER AQUIFER.

Ground-water flow between the water table zone and shallow artesian zones appears to be more complex. Water quality data from several ground-water pollution investigations indicates that contaminants introduced at the surface have migrated 20 to 30 m below land surface (bls) into the shallow artesian zone, within relatively small lateral distances (<100 m) from the source (i.e., Bridgeport Rental and Oil Services and Chemical Leaman Tank Lines) (DWR, 1982; NUS, Inc., 1984). This has occured in areas with relatively low pumping rates (<5 x 10^{-4} m^3/sec) (NUS, Inc., 1984; DWR, 1982).

2.2.4 Effects of Pumping Wells

The larger pumping centers in this area and their average pumping rates for 1980-1983 are; Monsanto (6.1 x 10^{-2} m^3/sec), Pureland Water Company (3.4 x 10^{-2} m^3/sec), Penns Grove Water Company (1.6 x 10^{-3} m^3/sec), and Rollins Environmental Services (RES, 1982 data; 5.2 x 10^{-3} m^3/sec) (DWR diversion files). Additionally, several local farms seasonally pump significant volumes of water from the shallow artesian aquifer. Monsanto's pumping has created the most significant depression of the potentiometric surface in the shallow artesian aquifer in the study area (see Figure 7). The drawdown caused by other wells (Pureland, Penns Grove, RES) is not obvious from Walker's (1983) data. However, pump test results show that the effects of these wells should not be discounted when considering flow patterns on a small scale (Geraghty and Miller, Inc., 1971; 1972; 1981).

2.2.5 Ground Water-Surface Water Relationships

Within the study area, the Delaware River is subject to tidal fluctuations. In October 1972, Geraghty and Miller, Inc. (1972) recorded a range of -0.61 - +2.4 m MSL for a single tidal cycle. Data collected from tide stage recorders located up- and down-river of the study area are summarized in Appendix 1. Hardt and Hilton (1969) report that the larger streams (Oldmans, Raccoon, and Repaupo Creeks) exhibit tidal fluctuations 8 to 9 kilometers (km) upstream from the Delaware River; whereas, smaller streams are tidally influenced only very close to the river.

Barksdale et al. (1958) conclude that the degree of interconnection between the aquifer and the Delaware River is largely controlled by the permeability of river bottom sediments. Local borings in the river bottom sediments show that the bottom is generally covered with fine grained sediments (New Jersey Geological Survey (NJGS), permanent notes). The permeability (laboratory measurements) of organic silts and clays taken from river bottom borings drilled just north of the Monsanto site, range from 1.00 x 10^{-6} m/sec to 8.53 x 10^{-11} m/sec (Woodward and Morehouse, Inc., 1972). Despite the apparent low permeability of the local river bottom, other data indicates that a greater interconnection exists between the aquifer and the river. For example, water quality data show higher than average chloride concentrations in wells located near the river and other brackish surface water bodies, indicating that low quality surface water is, in all probability, entering the aquifer (Geraghty and Miller, Inc., 1972; Betz, Converse, and Murdoch, Inc., 1981).

3.0 SUMMARY AND PROBLEM STATEMENT

At some sites in Logan Township, contaminants introduced at the ground surface have been found in the shallow artesian zone of the Kprm. The shallow artesian zone clearly behaves as a leaky artesian aquifer and the degree of interconnection between the water table and shallow artesian zones is spatially variable.

All recharge enters the aquifer locally in the form of precipitation or induced flow from bodies of surface water. The shallow artesian zone is recharged locally by vertical leakage from overlying water-bearing zones and surface water bodies. Therefore, rates and paths of vertical leakage control the vertical migration of contaminants. Discontinuities in confining layers undoubtedly play an important role in determining the paths of vertical ground-water flow. The discontinuous nature of the confining layers in this area is characteristic of fluviatile deposits. Also, unconformities between the Cretaceous and Quaternary units have led to the local development of discontinuous layers. Many hydrogeologic studies do not account for these discontinuities when making subsurface correlations. Preparation of detailed stratigraphic sections showing the extent of the confining layers in this area should be the first step in any hydrogeologic study. The purpose of this study was to develop reasonable models of the local hydrogeolgic regime within the study area.

4.0 APPROACH AND METHODS

In order to develop models of the local hydrogeologic regime, two general lines of investigation were pursued. Initially, correlations of surface and subsurface units were developed in as much detail as possible. The heavy mineral stratigraphy of the study area coupled with data from new and existing well and boring logs were the primary data. Lithofacies maps and cross-sections were developed to form a basis for interpretation.

Once the subsurface conditions had been established in the form of lithofacies maps and cross-sections, this information coupled with available site specific hydrogeologic information, was used to synthesize conceptual models of the local hydrogeologic regime. Pump test results, water level data, chemical and climatic data all contributed to the development of a model. The hydrogeologic models generated were then tested by computer simulation using the three-dimensional ground water flow model developed by Trescott (1975).

The specific methods employed in these two lines of approach are discussed in the following paragraphs.

4.1 GEOLOGIC METHODS

Surficial geology was established by interpretation of published geological maps, aerial photographs, and soil maps, and by examination of exposures in borrow pits. The geological maps used (and their scale) are Salisbury and Knapp (1909; 1:62,500), USGS (1967; 1:500,000), Johnson (1952; 1:250,000), and Hardt and Hilton (1969; 1:250,000).

Models of subsurface geologic conditions were developed in two steps. First, the heavy mineral composition of selected samples were determined using the procedures that are summarized in Appendix 2. These data were used in conjunction with data from other studies to establish a heavy mineral stratigraphy in the study area. It is assumed that the deepest occurrence of significant amounts of amphibole and pyroxene represents the minimum depth of Quaternary erosion and deposition. The pollen content of selected samples were identified and evaluated (Cotter, 1984; written communication) using the pollen extraction procedures of Faegri and Iverson (1964). The biostratigraphic column from Doyle (1977) was used to constrain the age of the appropriate stratigraphic intervals. Available lithologic and geophysical well logs were used to determine the distribution of lithofacies in the study area to the extent possible. It was assumed that the deepest occurrence of peat was an indication of the minimum amount of Quaternary erosion and deposition, because conditions did not favor the deposition and preservation of Cretaceous age peat. The absolute ages of Quaternary sediments could not be determined from available data.

The gross lithology and mineralogy of selected split spoon and drill cuttings samples were also determined.

Second, diagrams of inferred subsurface conditions were constructed from the accumulated data. The meandering river depositional models of Allen (1964) and Cant (1982) were used to help construct subsurface diagrams. Additionally, lithofacies maps of discrete subsurface intervals were used to refine interpretations of subsurface conditions.

4.2 HYDROGEOLOGIC METHODS

Published and unpublished water level and piezometric surface maps from several sites were evaluated to determine direction of flow, and gradient magnitude. Areas of aquifer recharge and discharge were identified from water level data, remote sensing data (i.e., LANDSAT infrared scans), and lithofacies maps and cross-sections. Aquifer discharge rates were estimated from observed gradients and aquifer characteristics.

The numerical model used in this study is a finite-difference model for the simulation of three-dimensional ground-water flow developed by Trescott (1975) and modified by Trescott and Larson (1976). Results of application of this model were used to further establish the relationships between local and regional ground-water flow. A detailed discussion of the computational method of the model is not included in this report.

5.0 RESULTS AND DISCUSSION

5.1 GEOLOGY

5.1.1 Topography

The study area is characterized by low, dissected, flat-topped hills separated by broad, swampy areas. There is commonly a noticeable break in slope between the uplands and swampy areas that is typically found at 0 to +2 m, MSL. Total relief is less than 10 m and generally is 3 to 5 m.

5.1.2 Stratigraphy

a. Pollen analysis

Table 5 shows the pollen derived ages of those samples that contained significant pollen. Sample locations are shown on Figure 8. The key used to determine the stratigraphic position of these samples is shown in Table 1a.

Table 5
Results of pollen analysis

Sample	Stratigraphic position
CL3-14	upper Patapsco-lower Raritan (zone 3)
CSP-4	lower (NJ) Raritan (zone 4)

There is a surprisingly large difference in age between the samples considering the distance between the sample locations.

Assuming that the outcrop trend is parallel to the strike of the formation, sample CSP-4 is, at a maximum, 5 m above sample CL3-14. This indicates that intraformational erosion was significant and/or that deposition rates were very small.

b. Heavy mineral analysis

Figure 9 is a summary plot of the results of the heavy mineral study. The average compositions of the Cretaceous units from Glaser (1969) and Groot (1955) are also plotted on the diagram. Results are tabulated in Appendix 2. In Figure 9, the end members of the compositional triangle are: zircon, tourmaline, and rutile; amphibole, pyroxene, garnet, and epidote; and, staurolite, kyanite, sillimanite, and all other non-opaques. Sample locations are shown on Figure 8. Three groups are delineated in Figure 9. Group C, characterized by less than 10 percent amphibole, pyroxene, epidote, and garnet; and, greater than 55 percent zircon, tourmaline, and rutile, seems to correlate with the heavy mineral suite of the Patapsco and Raritan. Group B, characterized by less than 10 percent amphibole, pyroxene, epidote, and garnet; and, less than 55 percent zircon, tourmaline, and rutile, seems to correlate with the heavy mineral suite of the Patuxent or Magothy. Group A, characterized by greater than 15 percent amphibole, pyroxene, epidote, and garnet; and, less than 55 percent zircon, tourmaline, and rutile, seems to correlate with the expected Quaternary heavy mineral suite.

Several samples have compositions which fall between Groups A and B, or A and C. These samples may be Quaternary age, implying

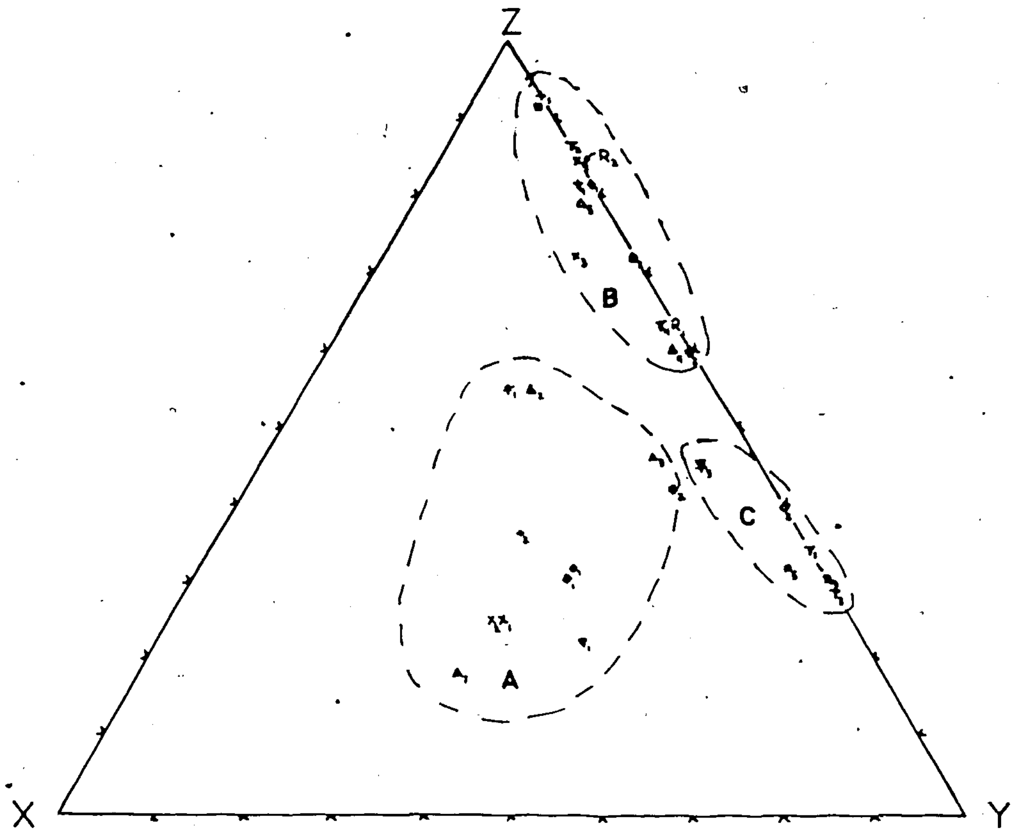


FIGURE 9. PLOT OF RESULTS OF THE HEAVY MINERAL STUDY.

X-GARNET+EPIDOTE+AMPHIBOLE+PYROXENE

Y-STAUROLITE+KYANITE+SILLIMANITE +OTHER NON-OPAQUES

Z-ZIRCON+TOURMALINE+RUTILE

that the subsurface intervals in which they are located, are composed of material reworked from Group A or B sediments with a small input of additional material. Alternatively, these samples may be Cretaceous age, implying that a full (immature) heavy mineral suite (with all the tectonic implications) was deposited in this area.

The presence of both Patapsco-Raritan and Patuxent or Magothy type heavy mineral suites can be explained by a change in sediment source area, progressive unroofing of the source area over a period of time, or local uplift of the source area during the northward shift of the Potomac-Raritan depocenter.

c. Distinction between Cretaceous and Quaternary deposits

In the absence of heavy mineral and pollen data, the presence of peat in boring logs was the criterion used to distinguish between Quaternary and Cretaceous deposits. The Quaternary depositional environment favored the deposition and preservation of peat but the Cretaceous depositional and post-depositional environments did not. Thick deposits of Quaternary peat and organic silt are recognized in logs from borings completed along the Delaware River and recent surface water drainage ways.

The thickness of Quaternary sand and upland deposits can not always be accurately determined from well log analysis because they are usually lithologically similar to the underlying Potomac Group. Yellow color, ascribed to the Quaternary deposits, has commonly been used to distinguish Quaternary from Cretaceous units, however yellow color appears to be common to both Quaternary and Cretaceous units.

For example, some yellow units have Potomac heavy mineral suites (samples 102-20, 107-45, CSP3) and some have Quaternary heavy mineral suites (samples CL4-10, 102-35, 104-35). Furthermore, comparison between various studies may not be accurate because color descriptions are not based on a common system (i.e., Munsell chart).

The occurrence of a Potomac type heavy mineral suite (sample 102-20) above a Quaternary type heavy mineral suite (sample 102-35) suggests that some of the Quaternary deposits are composed of reworked Potomac sediments. In-the-field distinction between Cretaceous and Quaternary units based on color or lithology is not reliable. Where distinction between units is important, some other method (i.e., pollen or heavy minerals) should be employed. Ideally, pollen content is the best stratigraphic tool.

d. Distribution of Quaternary and Cretaceous units

In general, Quaternary deposits appear to be thin (<2 m) to absent on upland areas and thicker (up to 30 m) under modern streams and swamps. This is consistent with observations by Salisbury and Knapp (1917) and Johnson (1937). The unclassified deposits, within the outcrop area of the Potomac Group and Raritan Formation, mapped by Salisbury and Knapp (1909) have Potomac Group heavy mineral suites and therefore appear to be erosional remnants of the Potomac Group.

Figures 10 through 15 were based on the results of pollen, boring log, and heavy mineral analyses, and field observations. Figure 10 is a contour map of the base of the Quaternary. Figure 11 is a diagrammatic cross section which illustrates the field relationships between the various lithologic units. Figures 12 through 15 are cross sections which illustrate the inferred subsurface distribution of Quaternary and Cretaceous units.

Results of the well log study indicate that Quaternary drainage patterns may have been quite different from modern drainage patterns. Thick accumulations of peat, organic rich silt, and sand are present under the Maple Swamp-Birch Creek area. The base of Quaternary contour map (Figure 10) shows a channel-like depression that trends nearly parallel to the river in this area. This depression may represent an abandoned channel of the ancestral Delaware River or Raccoon Creek.

Results of the heavy mineral study indicate that there may be exceptions to the aforementioned relationship between elevation and distribution of Quaternary units. In several borings drilled on upland sites, Quaternary type heavy mineral suites were observed at depths of 7 to 10 m bls (see Figures 10 and 15). The heavy mineral study, field observations, and previous mapping by Salisbury and Knapp (1909) indicate that there are at least two different ages of Quaternary upland deposits. The older deposit probably correlates with the Spring Lake or Van Sciver Lake beds of Owens and Minard (1979). It appears to be preserved as remnants of localized channel deposits. The younger deposit may correlate with the eolian Parsonburg Sand of Owens and Denny (1979). Field observations and previous mapping by Salisbury and Knapp indicate that this unit is thin and discontinuous.

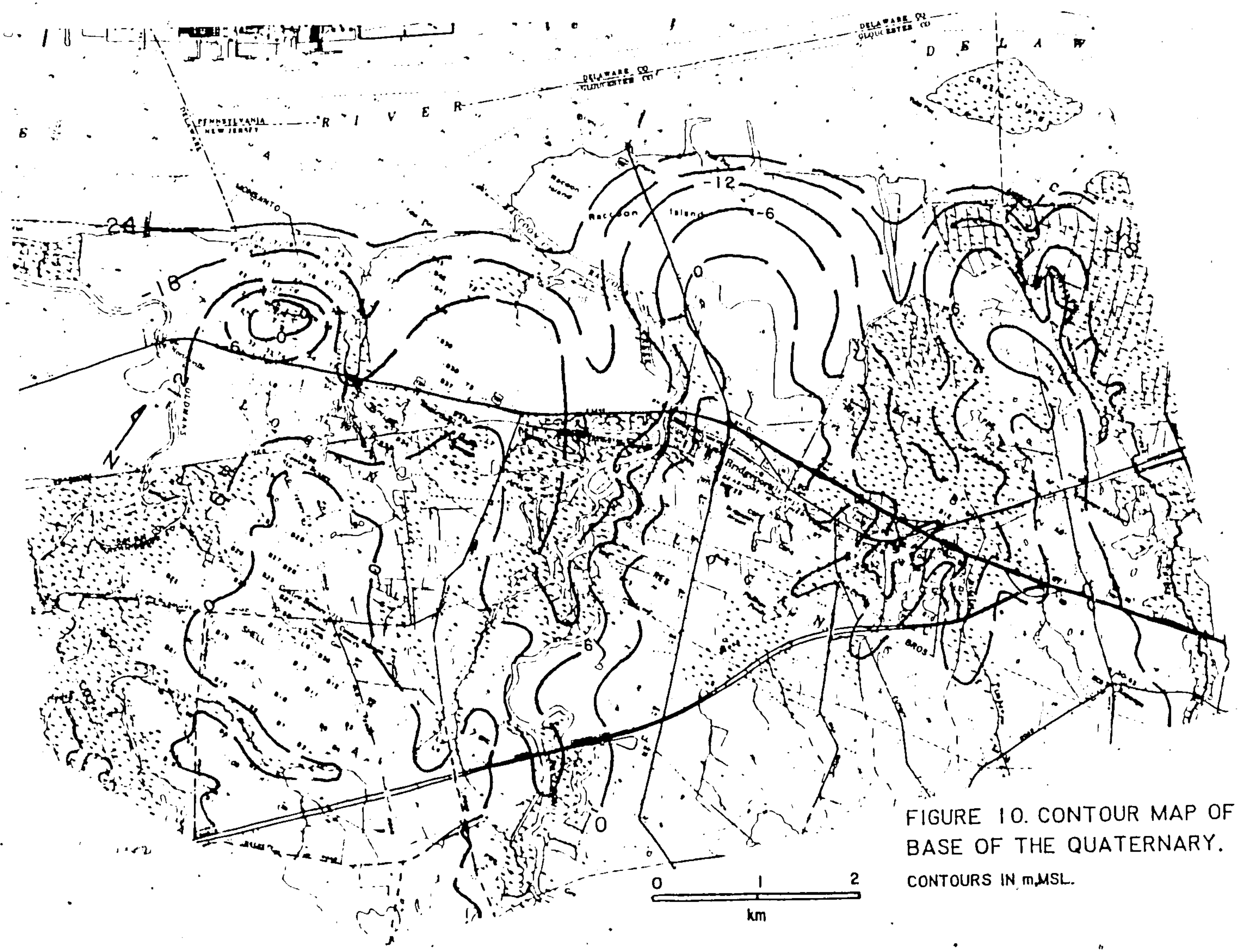


FIGURE 10. CONTOUR MAP OF THE BASE OF THE QUATERNARY.

CONTOURS IN m MSL.

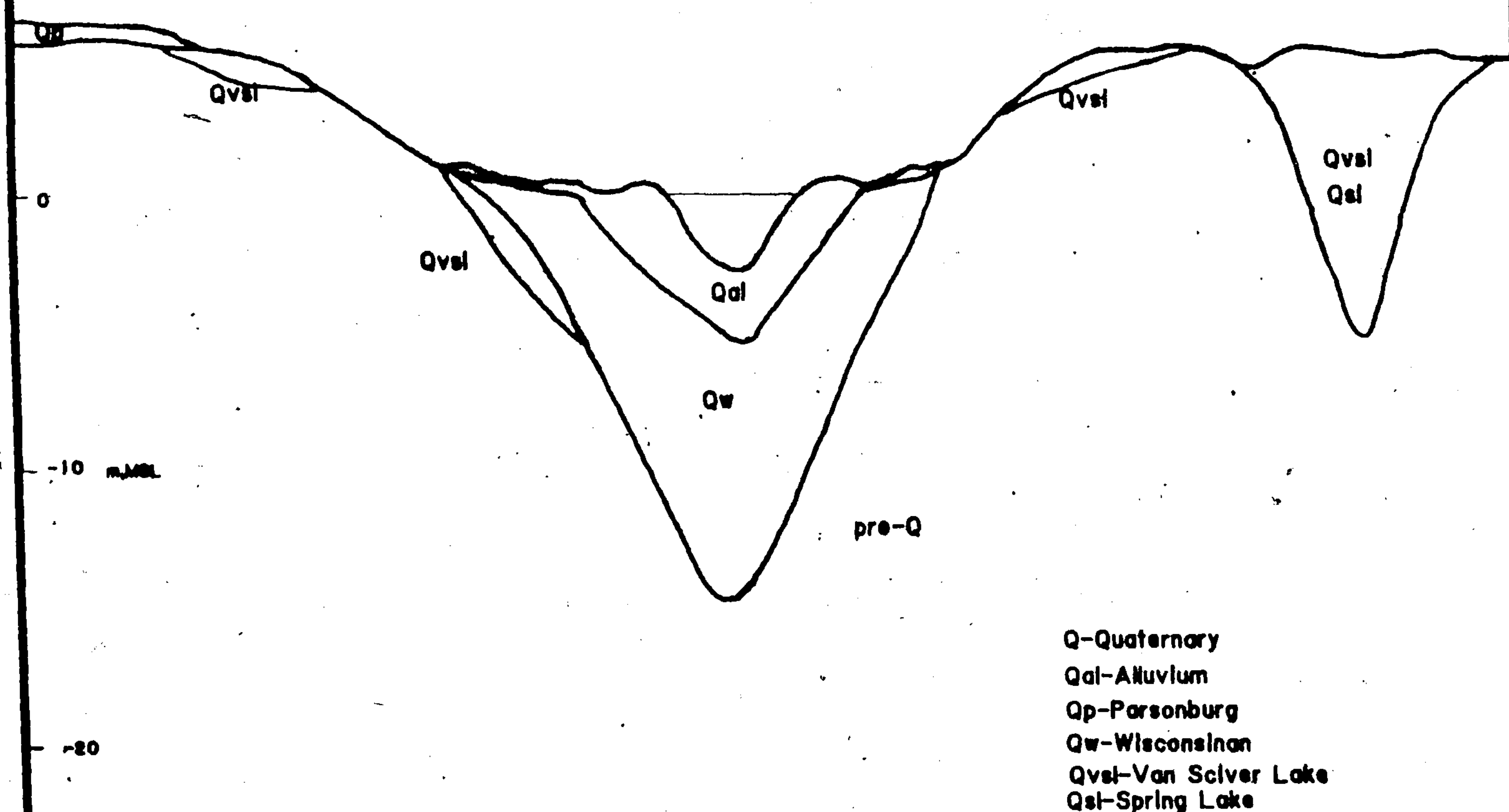


FIGURE 11. DIAGRAMMATIC CROSS SECTION.

EXPLANATION FOR FIGURES 12-15,19

SAND

CLAY/SILT

SAND WITH CLAY/SILT LAYERS LESS THAN 0.3m THICK

PEAT AND ORGANIC RICH SILT/CLAY

L8 BORING OR WELL

▲ BOTTOM OF BORING

WELL SCREEN

Kprm-1-LOWER AQUIFER

Kprm-2-MIDDLE AQUIFER

Kprm-3-UPPER AQUIFER

Q-QUATERNARY

K-CRETACEOUS

Q-K BOUNDARY

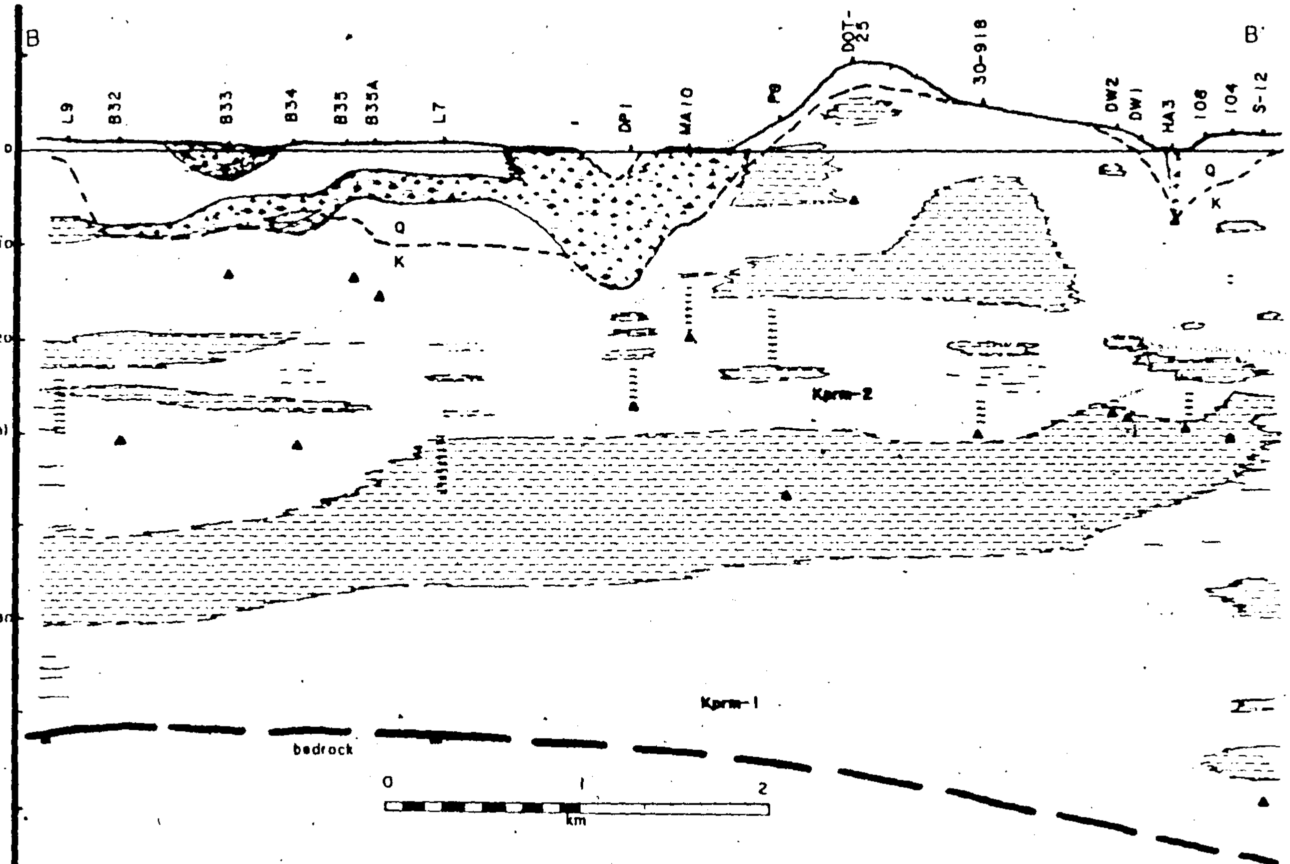


FIGURE 12. CROSS SECTION B-B'

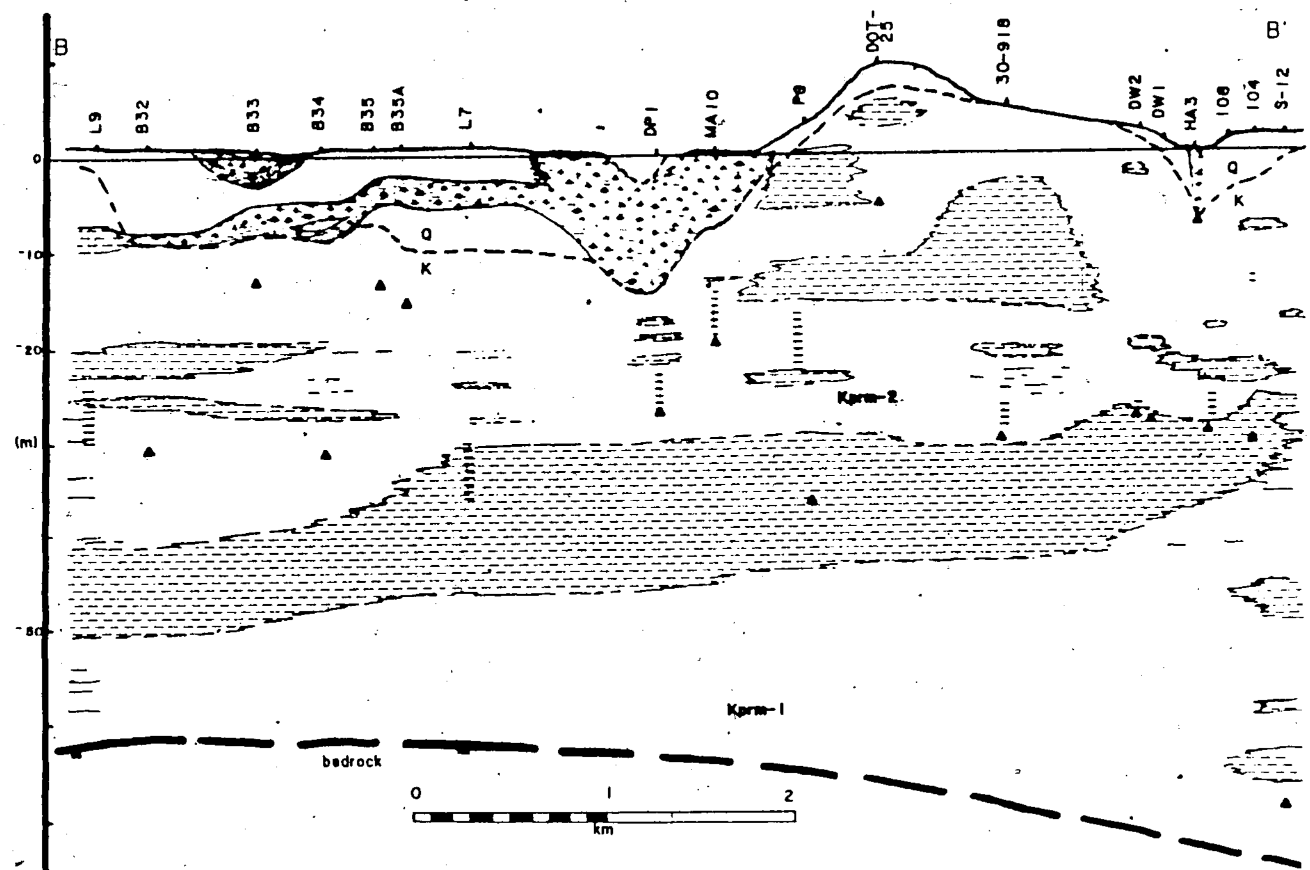


FIGURE 12. CROSS SECTION B-B'

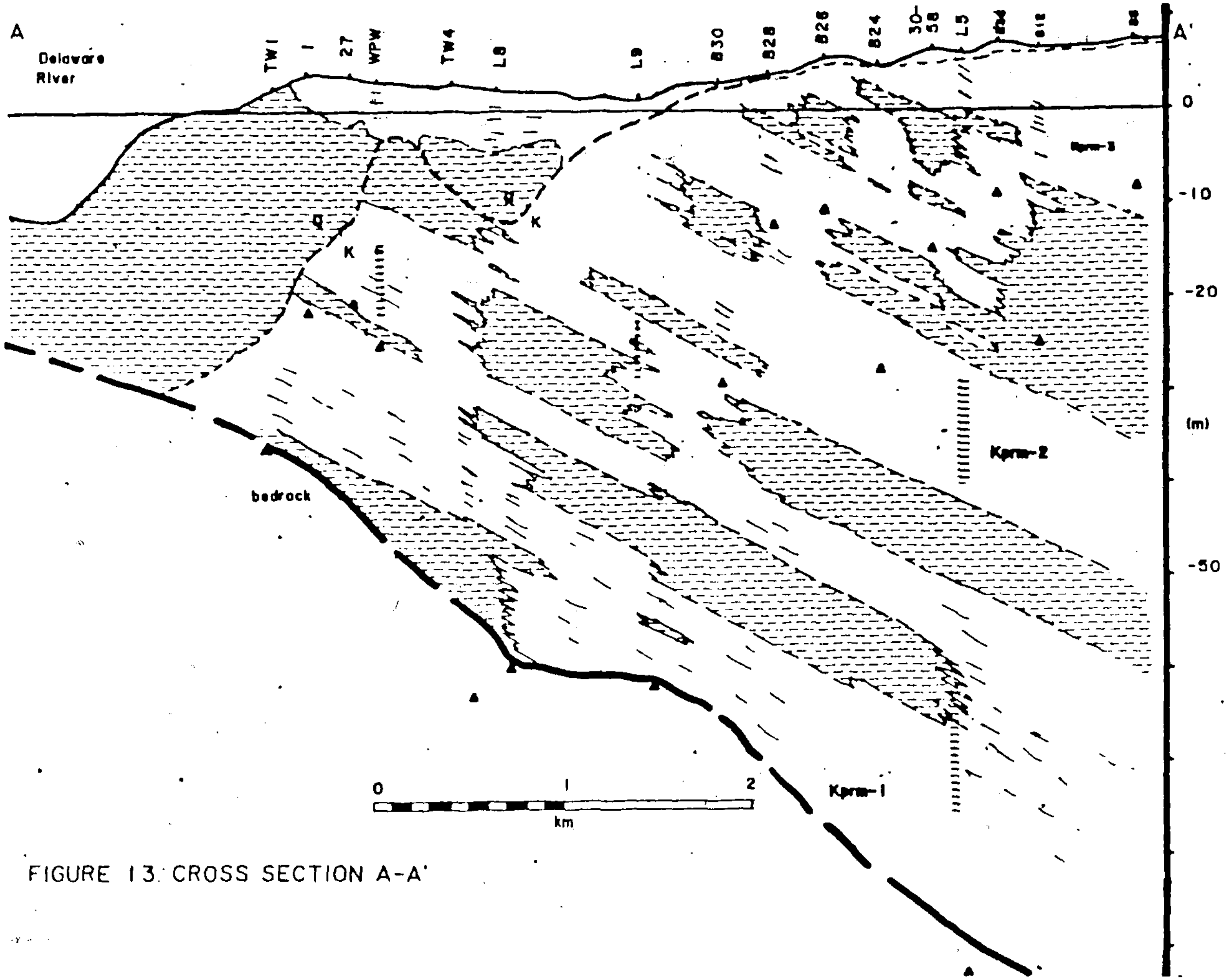


FIGURE 13: CROSS SECTION A-A'

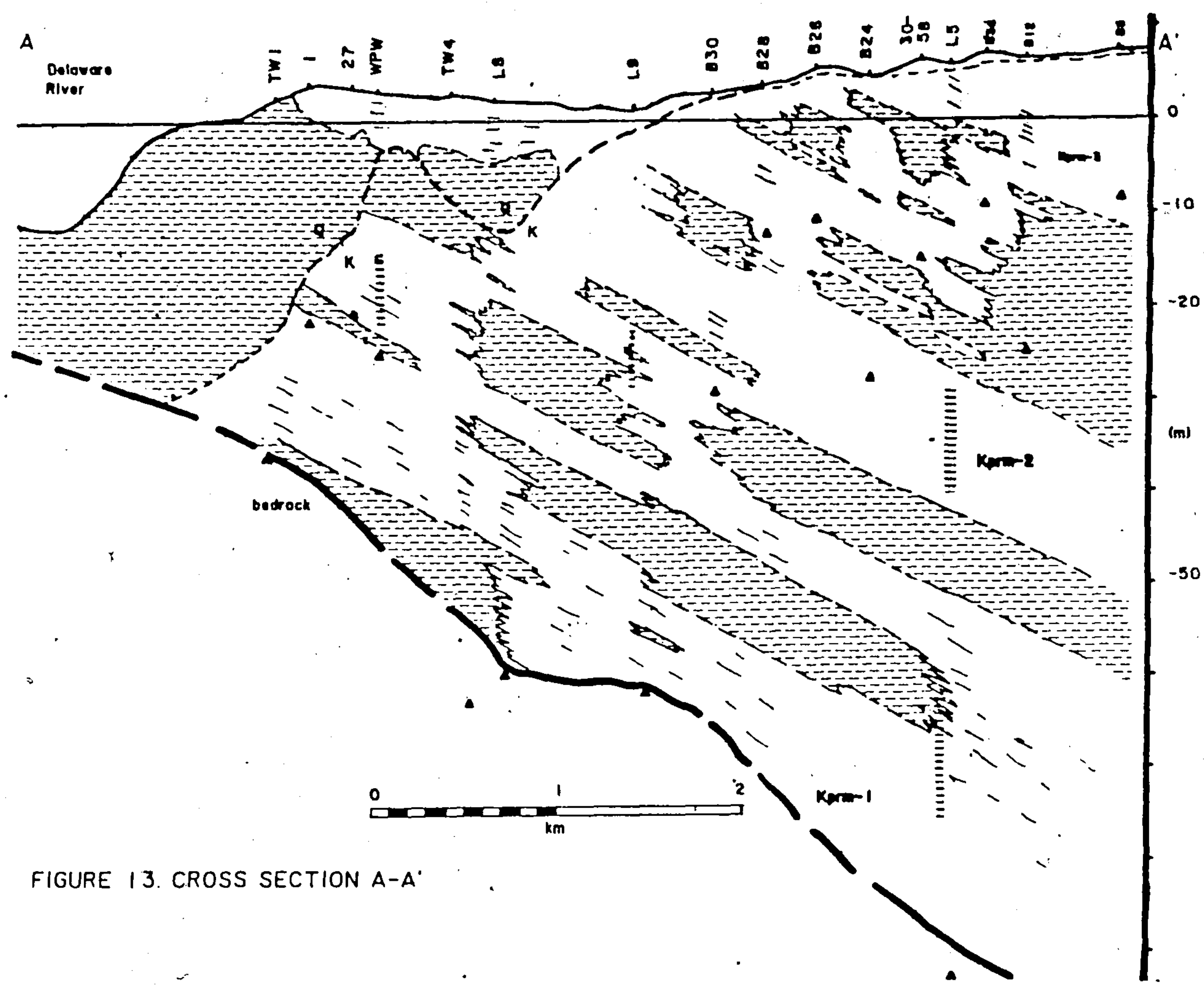


FIGURE 13. CROSS SECTION A-A'

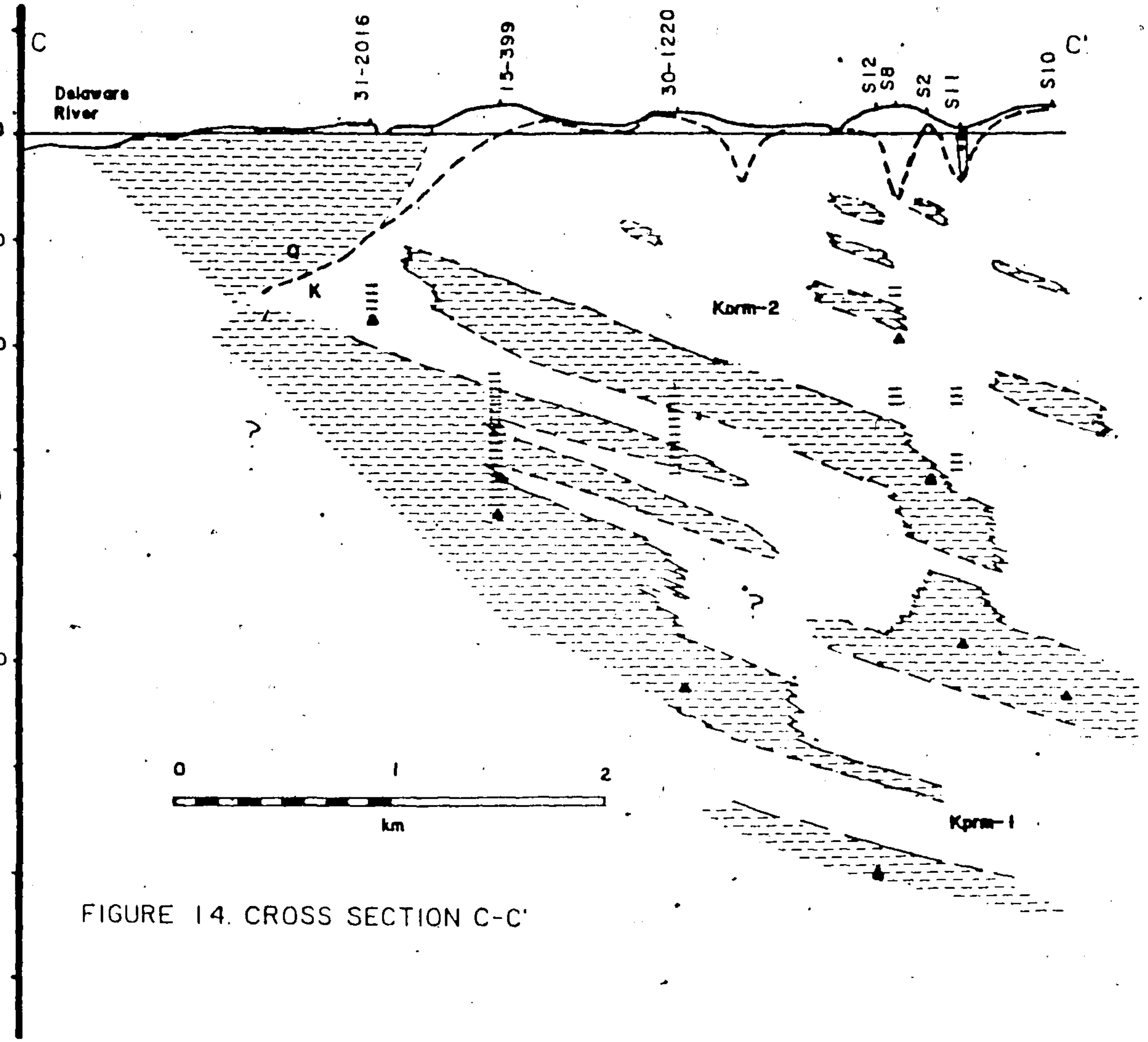


FIGURE 14. CROSS SECTION C-C'

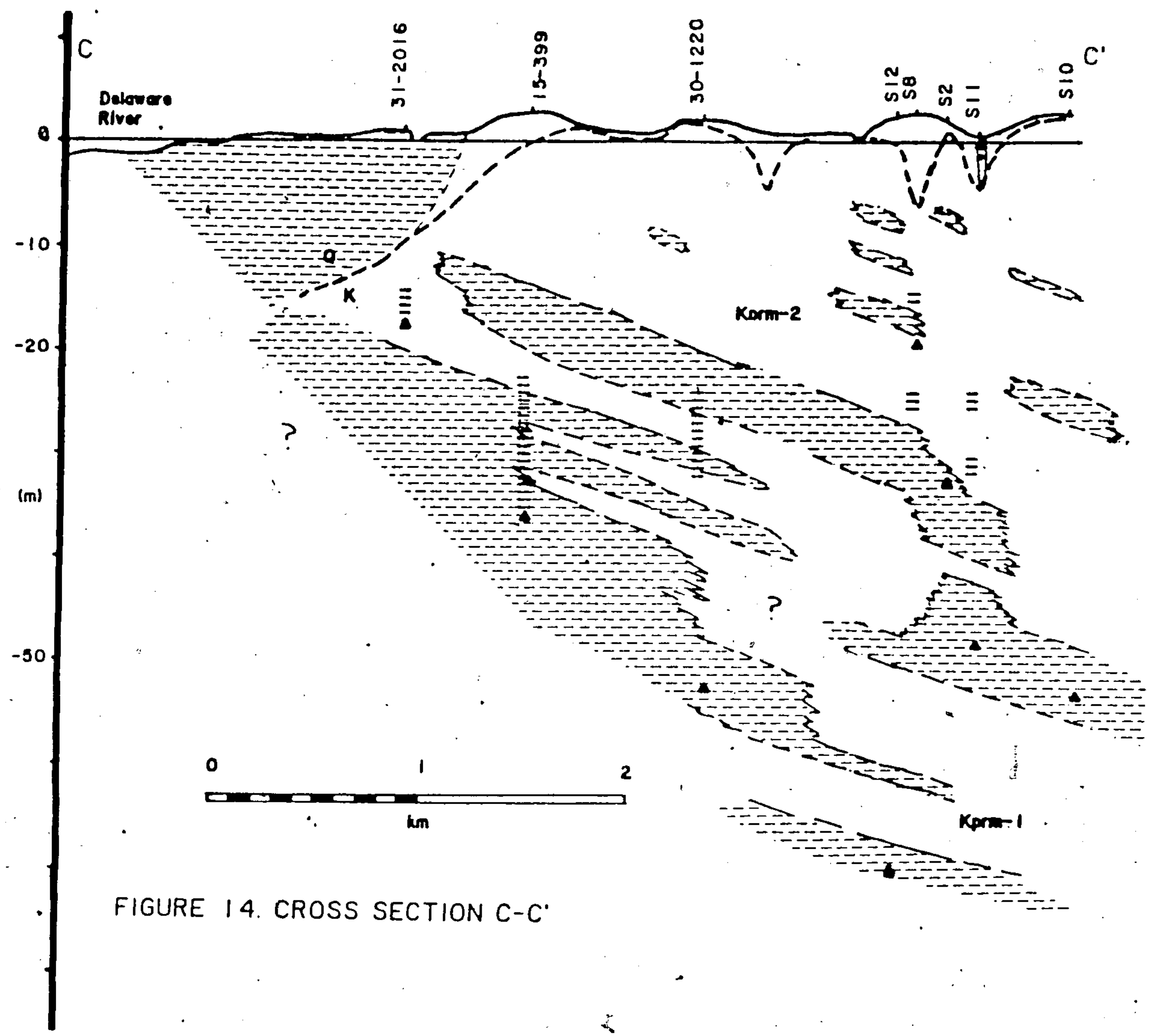


FIGURE 14. CROSS SECTION C-C'

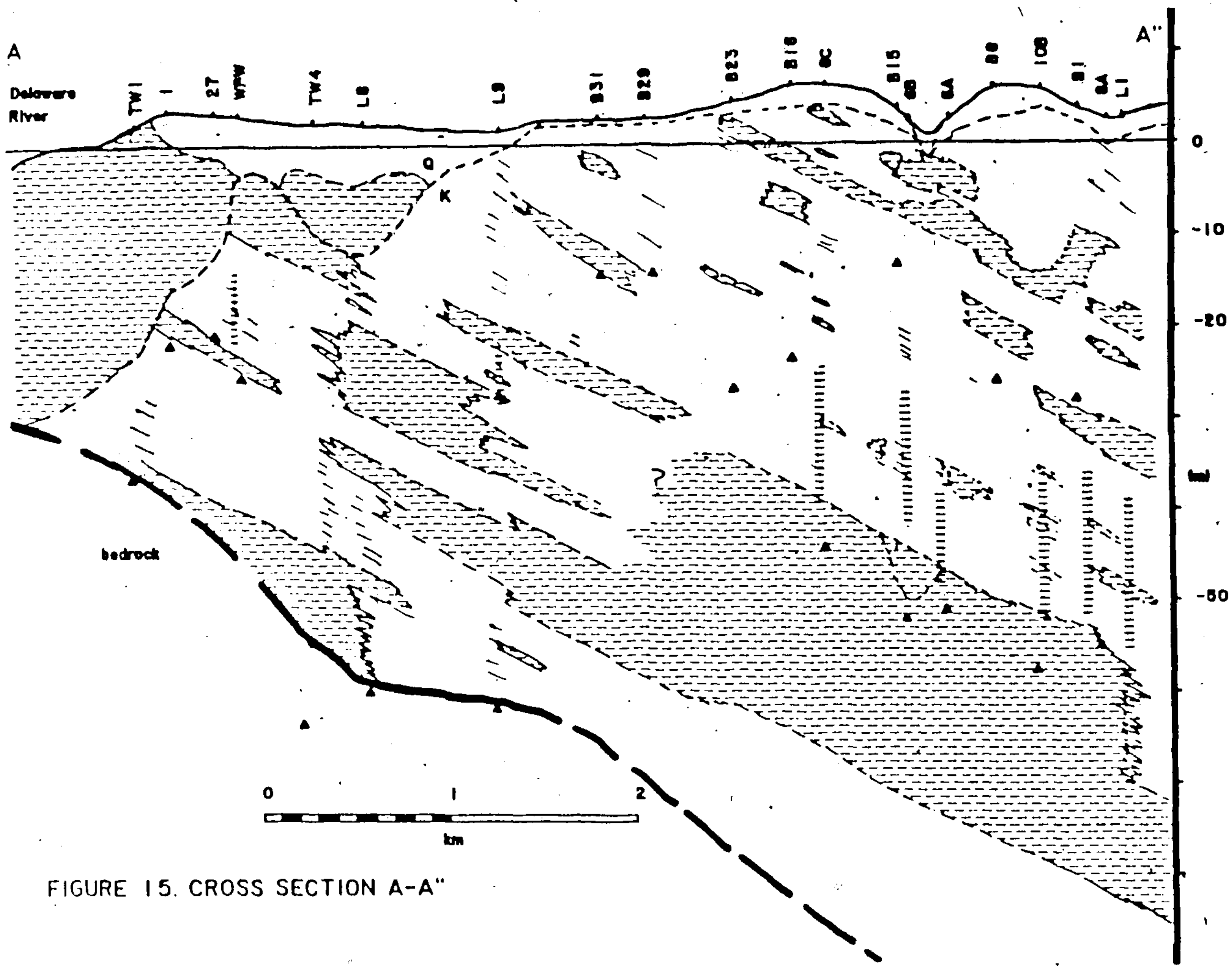


FIGURE 15. CROSS SECTION A-A"

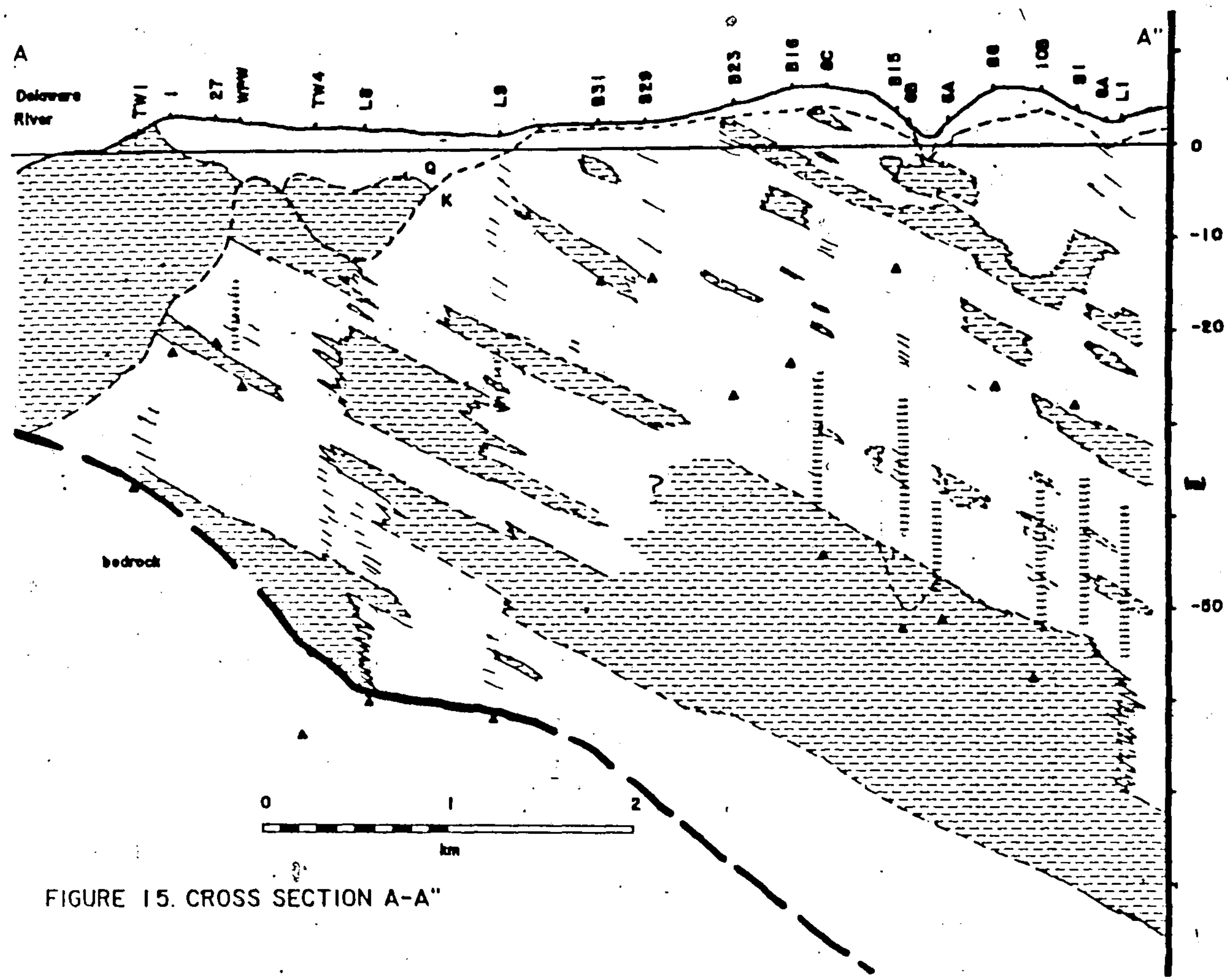


FIGURE 15. CROSS SECTION A-A''

Previous work by Owens and Denny (1979) and Owens et al. (1983) indicates that several different ages of Quaternary lowland deposits should be present in the study area. The units can range in age from Sangamon (Spring Lake beds) to recent (Owens and Minard, 1979; Owens et al., 1974). The multiple regressive-transgressive cycles undoubtedly ha[illegible] created complex erosional-depositional relationships between the different units (Demarest et al., 1981). However, the existing data are not sufficient to distinguish between the different age units.

The distinct break in slope between uplands and lowlands strongly suggests that the lowland sediments were deposited in erosional channels cut into the upland areas. No evidence of a facies change was observed. The lowland deposits are therefore younger than some of the upland deposits. The relation between the lowland and eolian upland deposits was not observed. However, channel incision and eolian deposition were occurring during the periods of glacial maxima (Owens, 1974; Denny et al., 1979), and therefore the deposits must be, at least in part, correlative. These relationships are illustrated in the diagrammatic cross section (Figure 11).

e. Mans activity

Within the past 50 years, large volumes of dredge spoil from the Delaware River have been disposed of in marshes and abandoned gravel pits located along the Delaware River. Field observations indicate that the composition of this material is highly variable.

5.1.3 Lithology and Lithofacies Analysis

a. Character of Cretaceous deposits

The character of Cretaceous deposits was observed in outcrops and split spoon samples. Detailed descriptions are included in Appendix 3. Locations of outcrops and selected borings are shown in Figure 8. Figure 16 is a drawing of one outcrop which is typical of the lithologies and sedimentary structures observed in most of the other Cretaceous exposures. Similar lithologies and evidence of similar sedimentary structures also were present in the split spoon samples.

Deposits are informally classified as predominately sand or predominately clay/silt. Predominately sand deposits are composed of locally lignitic, poorly sorted, subangular to subround, fine to coarse, quartzose sand and gravel, with a trace of clay/silt. The sands are white, gray, and shades of yellow and red. Staining by iron oxide is ubiquitous.

In most cases, the boundaries of individual beds are erosional. Beds are preserved as 0.25 to 1.5 m thick lenticular bodies. The lateral extent of an individual bed usually can not be observed in outcrop, due to poor exposure or intraformational erosion. A vertical sequence may be 1 to 20 m thick, and composed of tens of beds. Individual beds either are trough cross bedded or exhibit uniform, massive bedding. Beds which grade from non-stratified at the base to cross bedded at the top are rarely found. A basal lag gravel is common. In some cases, gravel sized clay galls were found

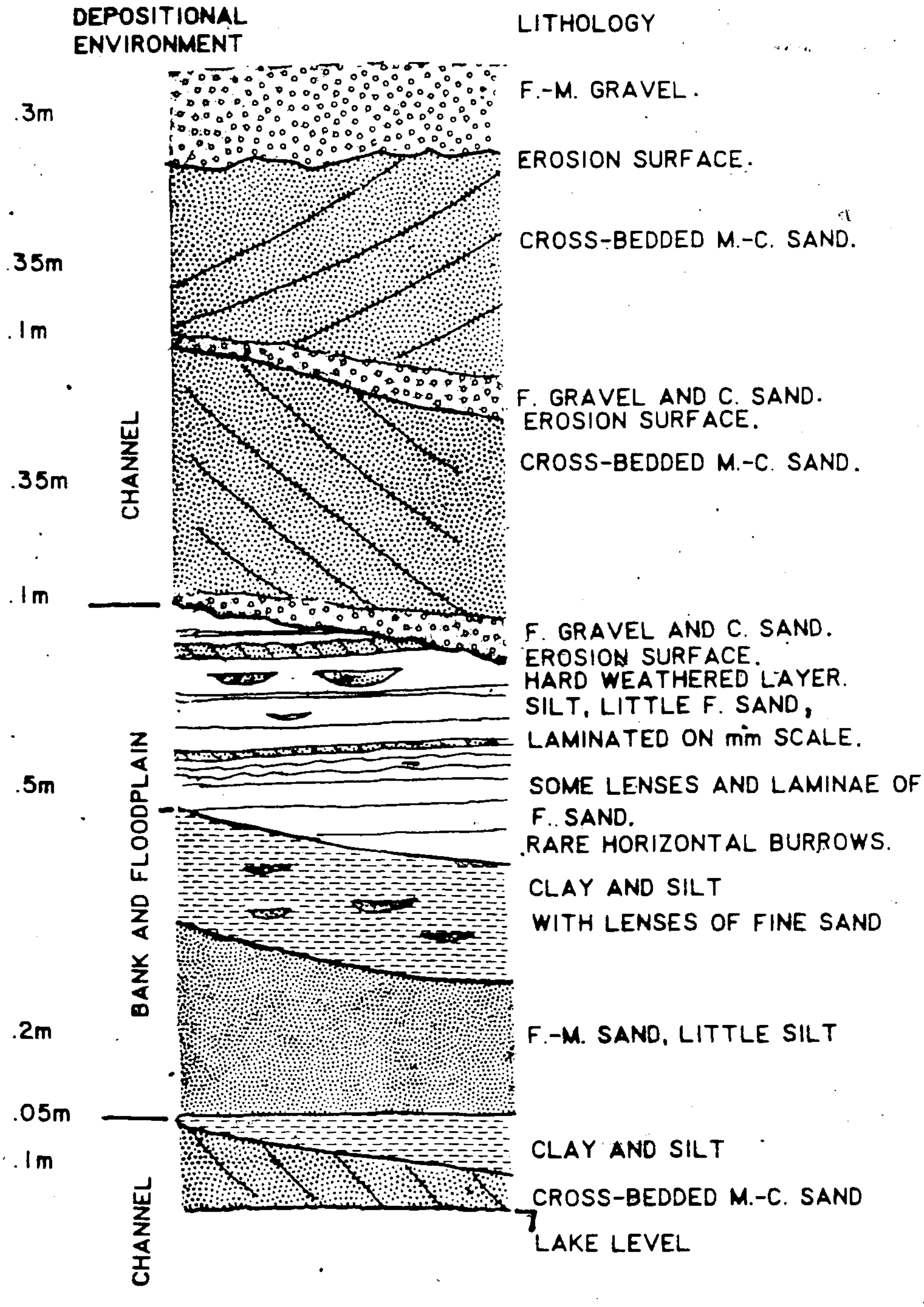


FIGURE 16. OUTCROP DESCRIPTION. SOUTH SIDE OF COOPER LAKE.

in the basal lag gravel. Fining upward trends in grain size are commonly seen in individual beds and over a vertical sequence of several beds.

Predominately clay/silt deposits are composed of laminated (mm scale) clay and silt/sand or massive clay and clay/silt. In some split spoon samples and outcrops, clays and silts are intermixed with sand and gravel. Soft sediment deformation structure (slumps) may be present.

Based on the organic content, at least two types of predominately clay/silt deposits are represented. Beds with abundant visible organic matter (>10 percent) usually have a darker, greener color than beds without abundant organic matter. The organic matter is predominately finely disseminated plant remains. It is these organic-rich beds that contain pollen. Beds with abundant organic matter also contain pyrite and/or marcasite as concretions, finely disseminated grains, or concentrations along nearly horizontal laminae. Beds without abundant visible organic matter (<1 percent) are light gray, white, shades of yellow and red, or mottled or variegated shades of red, yellow, and purple. Organic matter, if present, is lignite. Iron oxides may be concentrated along laminations, in sand layers, and/or at bed boundaries. Small iron oxide concretions may be present in the intensely colored beds.

In outcrop, organic-poor beds are 0.05 to 1 m thick. From split spoon samples and well logs, a vertical sequence may range from a few centimeters to approximately 10 m thick. In outcrop, the lateral extent of these beds ranged from about 1 m to large bodies of unknown dimensions. The organic-poor, thinly laminated beds have planar lower boundaries which seem to be conformable to underlying beds; whereas, the organic-poor, massive beds have planar, curved, or irregular lower boundaries, and may be unconformable to underlying beds. The nature of the lower boundaries of organic-rich units was not observed.

In outcrop, beds show a range of shapes and sedimentary structures. They range from thin (15-30 cm) lenticular or tabular bodies, to bodies that are tens to hundreds of meters in lateral extent. Small lenticular beds may be found at the base of larger, lenticular shaped, trough cross bedded sand units. Ripple marks, alternating clay and silt laminae, and burrows are commonly observed. It is not always clear whether or not these clay/silt units occur as part of a fining upward sequence. The field relations between the larger fine grained units and the surrounding formation could not be observed because of poor exposure.

In the Bridgeport area, the organic-poor beds are much more common than the organic-rich beds. Potomac/Raritan age, organic-rich beds are seen in only four borings (CL3, AF, NGCC, L9), and in outcrop at Curtis Sand, Logan Liquors, and Paz Brothers Sand (see Figure 8 for locations).

b. Lithologic and geophysical well logs

Similar lithofacies are observed in other lithologic logs from the surrounding area. Figures 17a and 17b show interpretive geophysical and lithologic well logs of Potomac Group deposits from Maryland, Delaware, and the study area. The sharp basal erosional contacts, abrupt lithologic changes, fining upward sequences, plant remains, and a lack of marine fossils are all indicators of shifting channel deposition in a fluvial environment (Cant, 1982).

c. Character of Quaternary deposits

Results of field observations, well log analyses, and previous studies indicate that two different Quaternary lithofacies are present in the study area. Generally, organic-rich clay/silt or clayey-silty organic facies are found beneath modern streams and swamps; whereas, fine to coarse sand with minor gravel and/or clay interbeds are found beneath upland areas. Evidence of a facies change between these two types of materials was not observed. This possibility cannot be discounted however, because exposures of Quaternary deposits are lacking and well log data is insufficient.

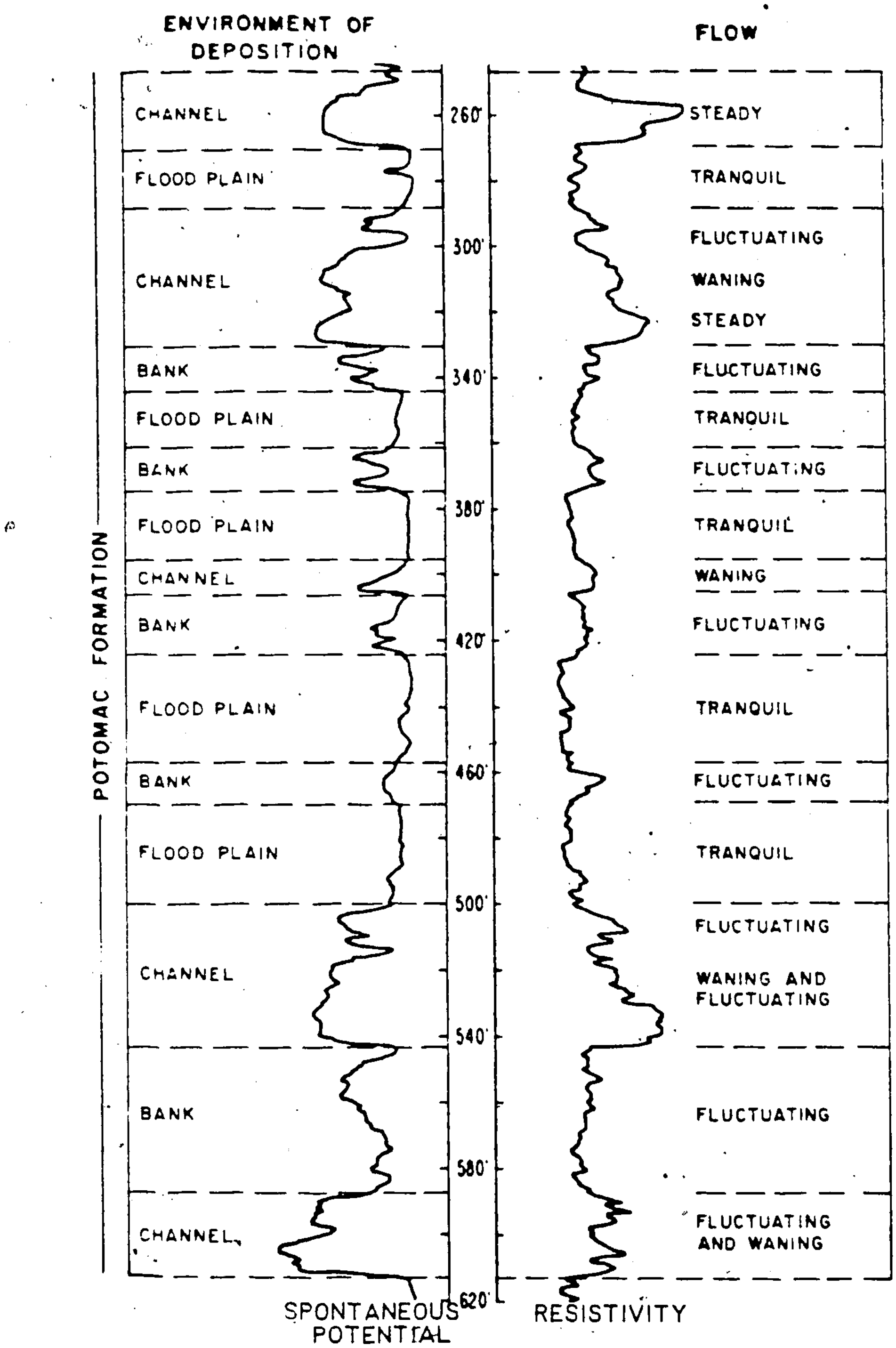


FIGURE 17a. INTERPRETIVE GEOPHYSICAL LOG. FROM SPOLJARIC (1967)

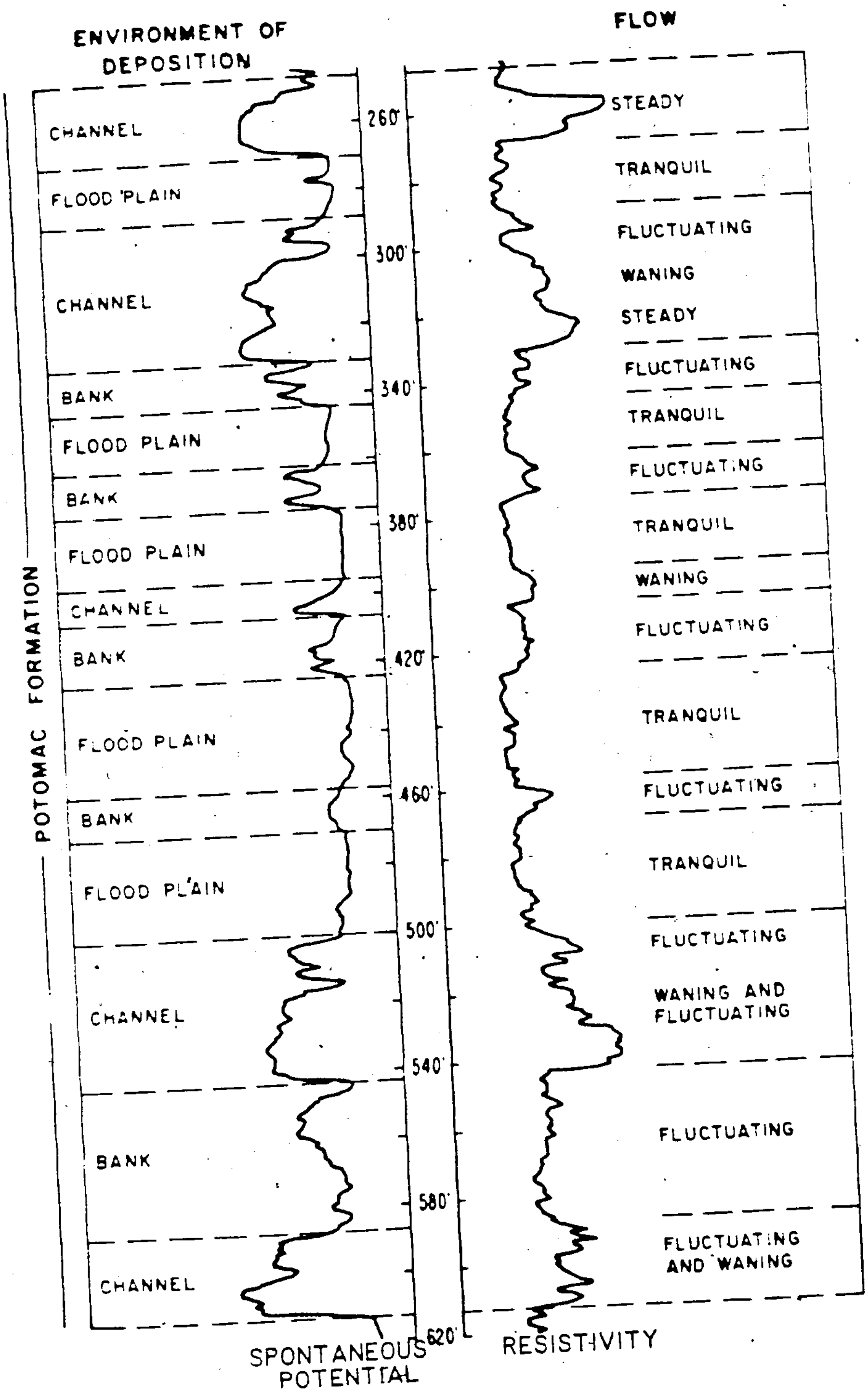


FIGURE 17a. INTERPRETIVE GEOPHYSICAL LOG. FROM SPOLJARIC (1967)

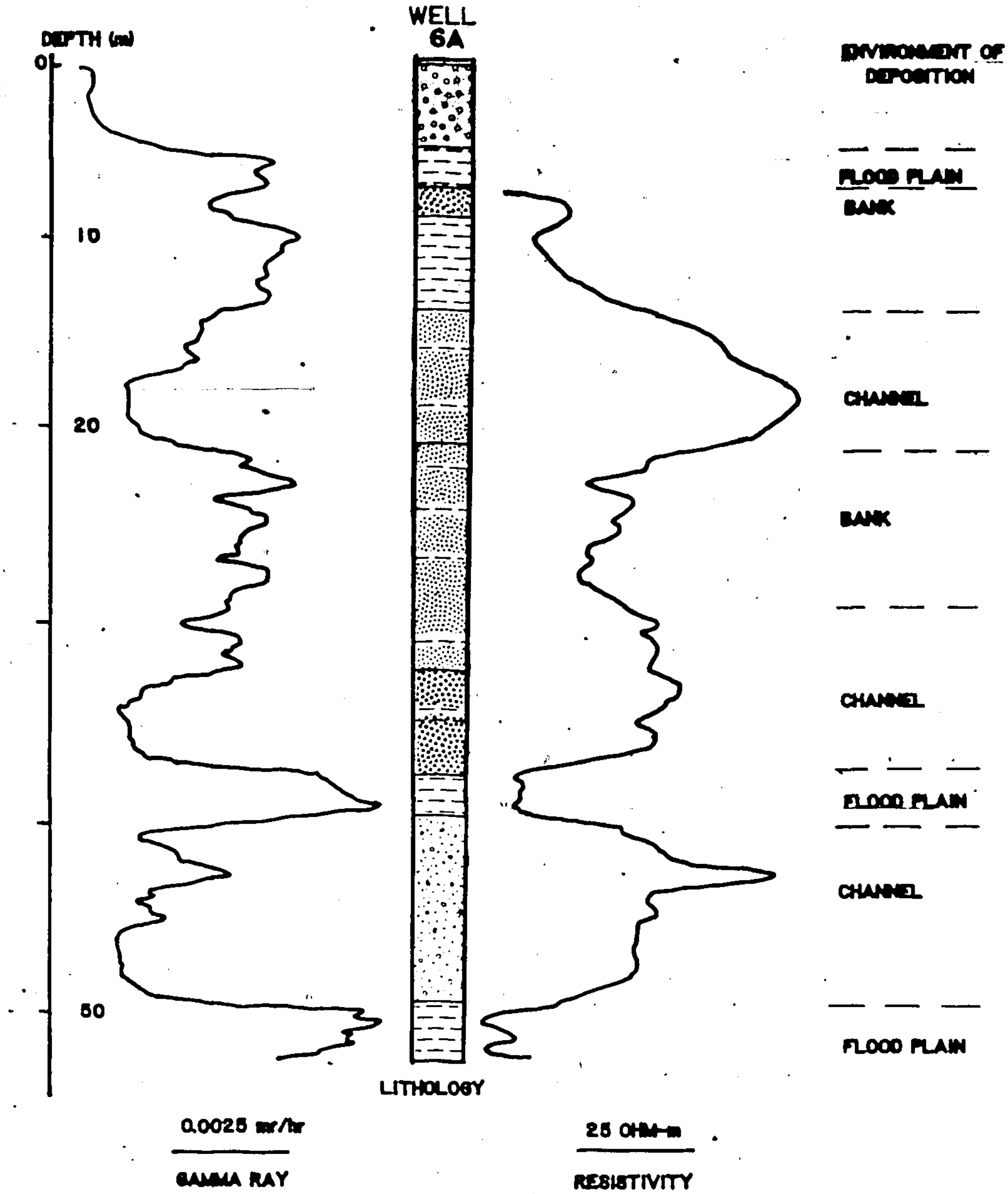


FIGURE 17b. INTERPRETIVE GEOPHYSICAL LOG

CLAY
SAND AND GRAVEL
GRAVEL SOME SAND
FINE SAND
MEDIUM TO COARSE SAND

d. Lithofacies analysis

The results of the lithofacies analyses are presented in Figures 18a through 18f as contour maps of thickness of the lithofacies units over a 9.1 m (30 foot), 18.2 m (60 foot), or 30.5 m (100 foot) interval. Data are tabulated in Appendix 4. In these analyses, peat is considered to be part of the clay/silt lithofacies. Selected base of Quaternary contours are also shown where Quaternary erosion and sedimentation are significant.

It is important to consider the dip of the Cretaceous units when interpreting the lithofacies maps. A Northwest to Southeast transect across the area encounters progressively younger Cretaceous units. Additionally, a bed which lies within the specific interval in the Northwest part of the area may lie below that interval in the Southeastern part of the area. This factor is most important in the 9.1 m and 18.2 m interval lithofacies maps.

The +3 to -6 m maps (Figures 18a and 18b) show that the Quaternary units are primarily clay/silt or organic material. Again, Quaternary sand units are difficult to recognize. The Cretaceous deposits in this interval are primarily composed of sand, which lithofacies patterns indicate become thicker and more widespread upsection. Lithofacies patterns indicate marked lithologic changes within short distances. Clay/silt lithofacies patterns indicate that clay/silt bodies are discontinuous over the area. Large areas have less than 1.5 m of clay/silt. Fifteen borings showed no clay/silt in this interval.

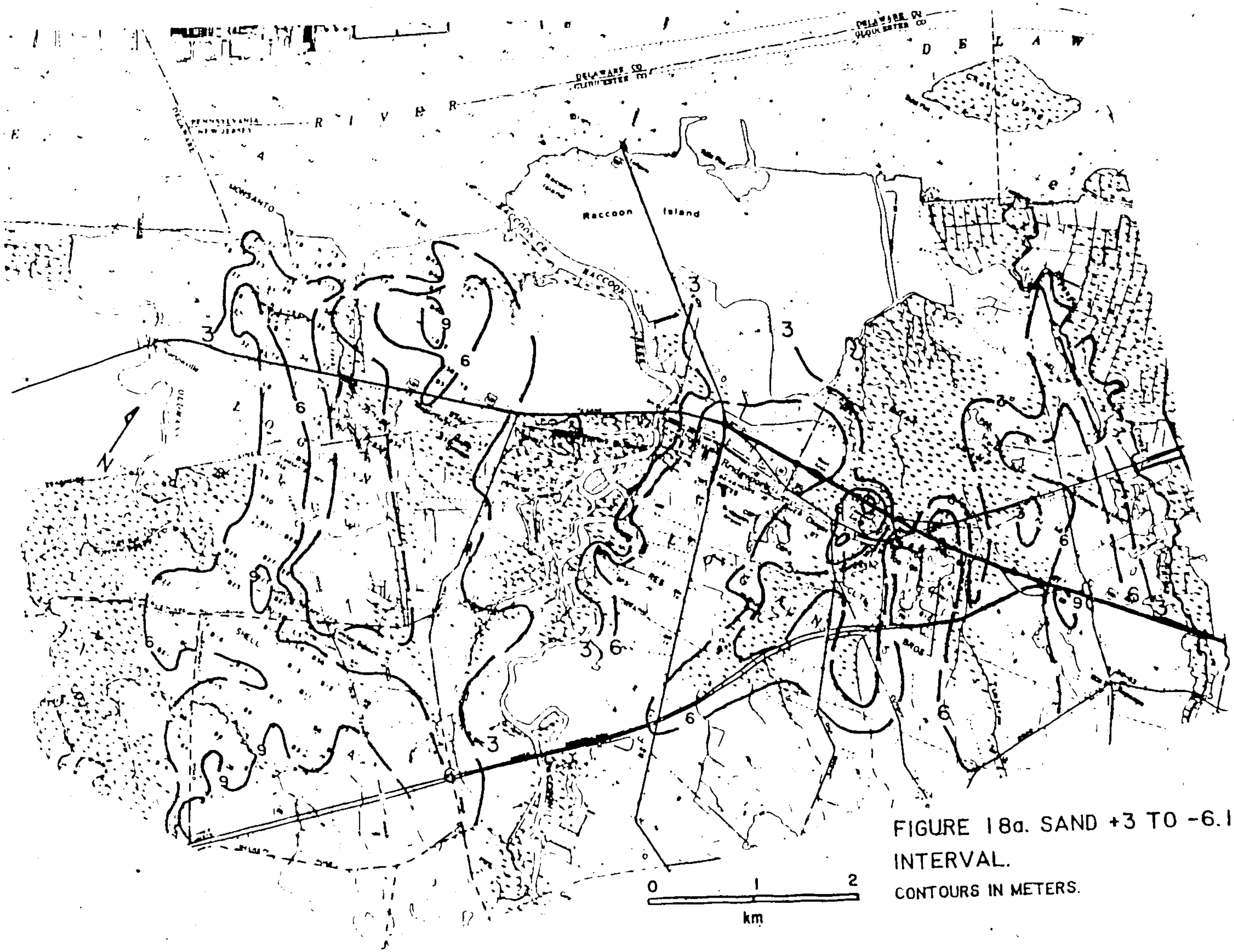


FIGURE 18a. SAND +3 TO -6.1m,MSL INTERVAL.
CONTOURS IN METERS.

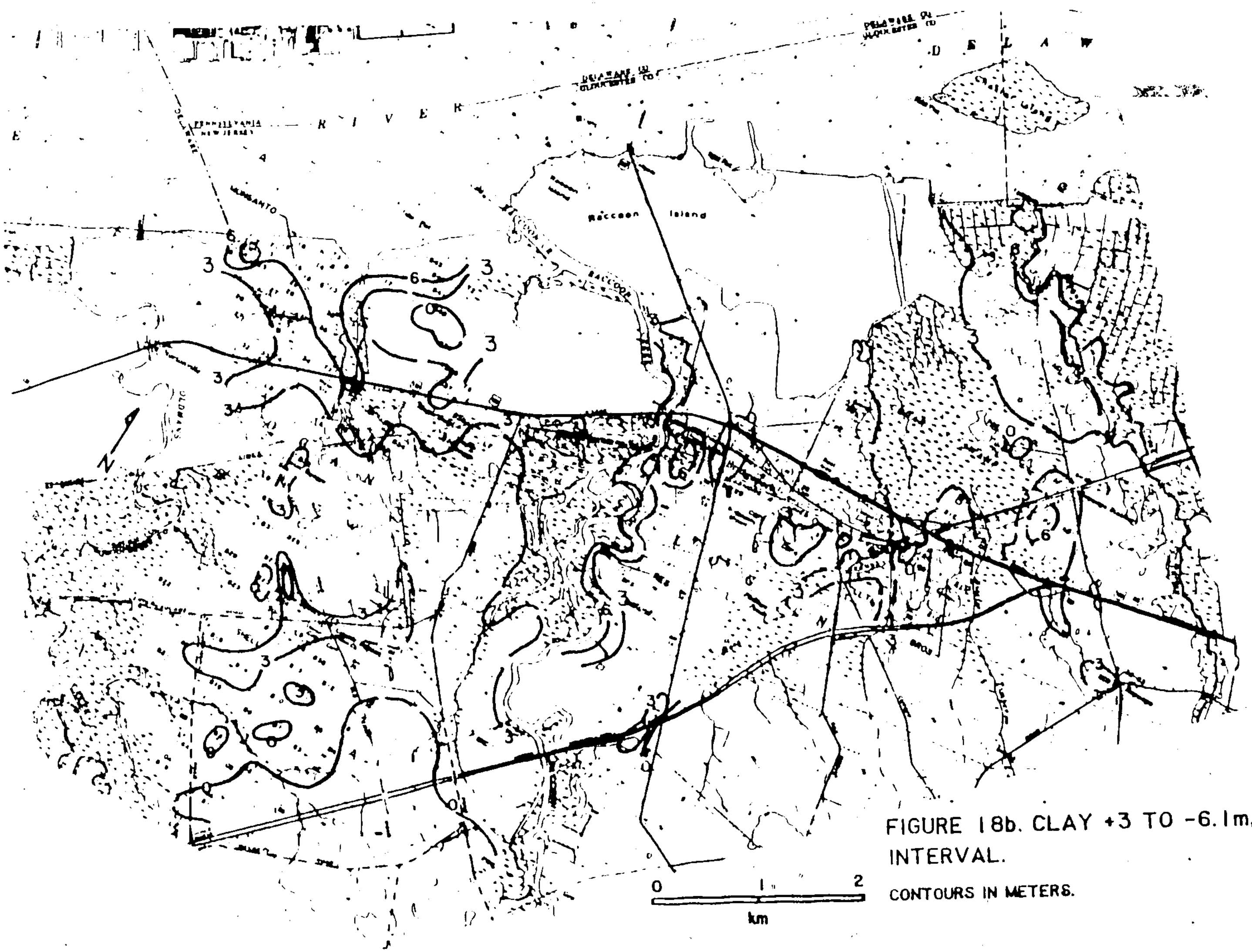


FIGURE 18b. CLAY +3 TO -6.1m,MSL INTERVAL.

CONTOURS IN METERS.

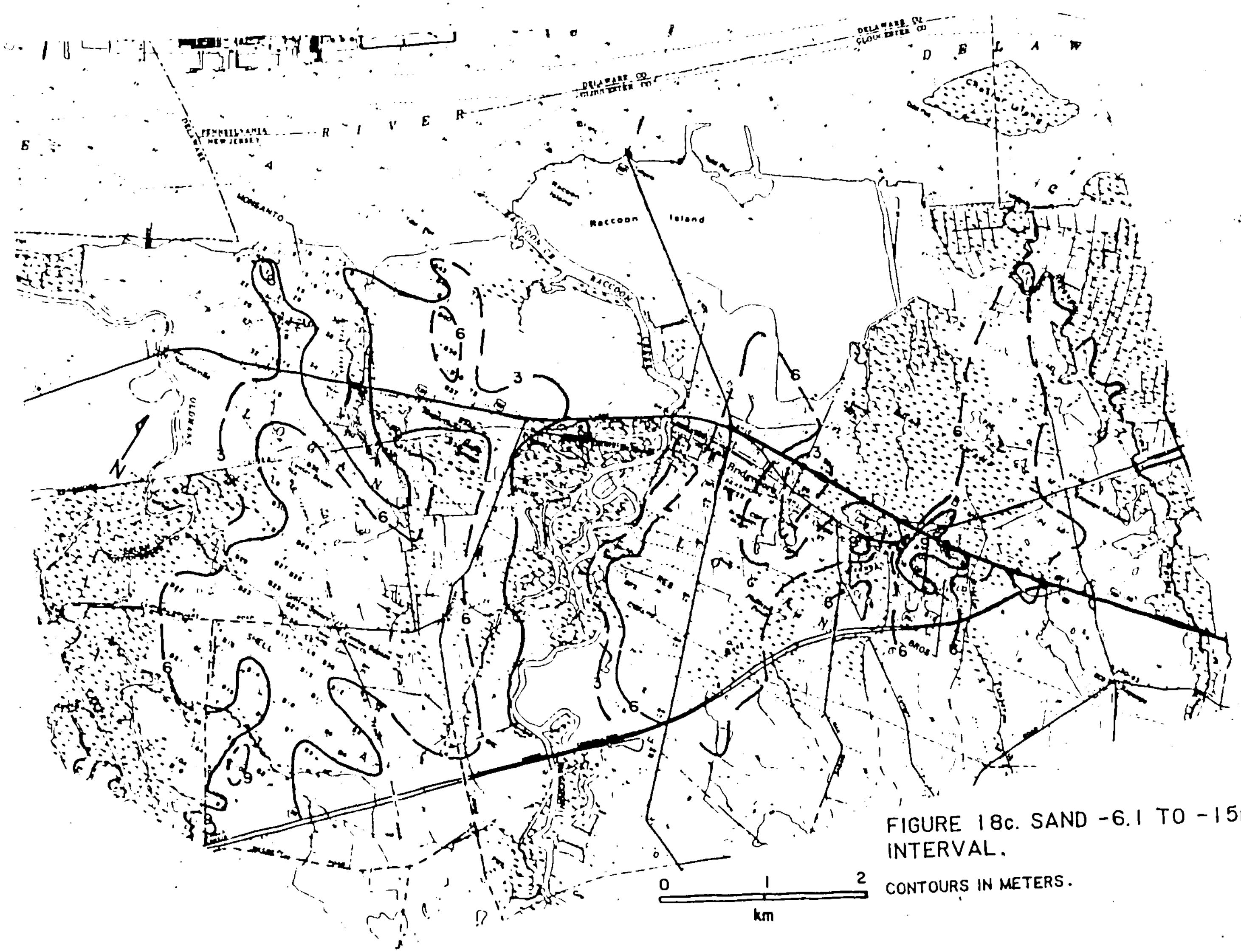


FIGURE 18c. SAND -6.1 TO -15m,MSL INTERVAL.

CONTOURS IN METERS.

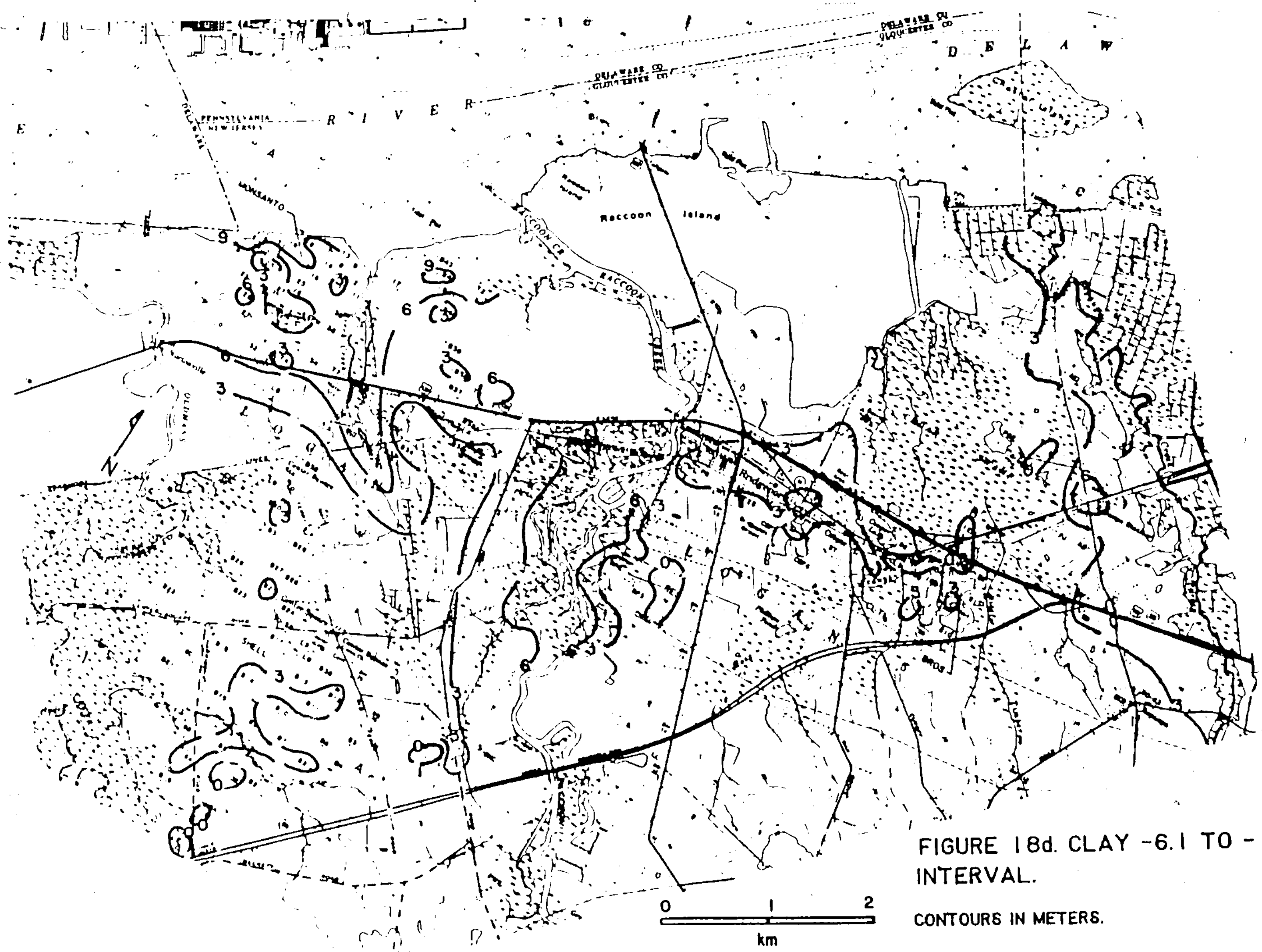


FIGURE 18d. CLAY -6.1 TO -15m,MSL INTERVAL.

CONTOURS IN METERS.

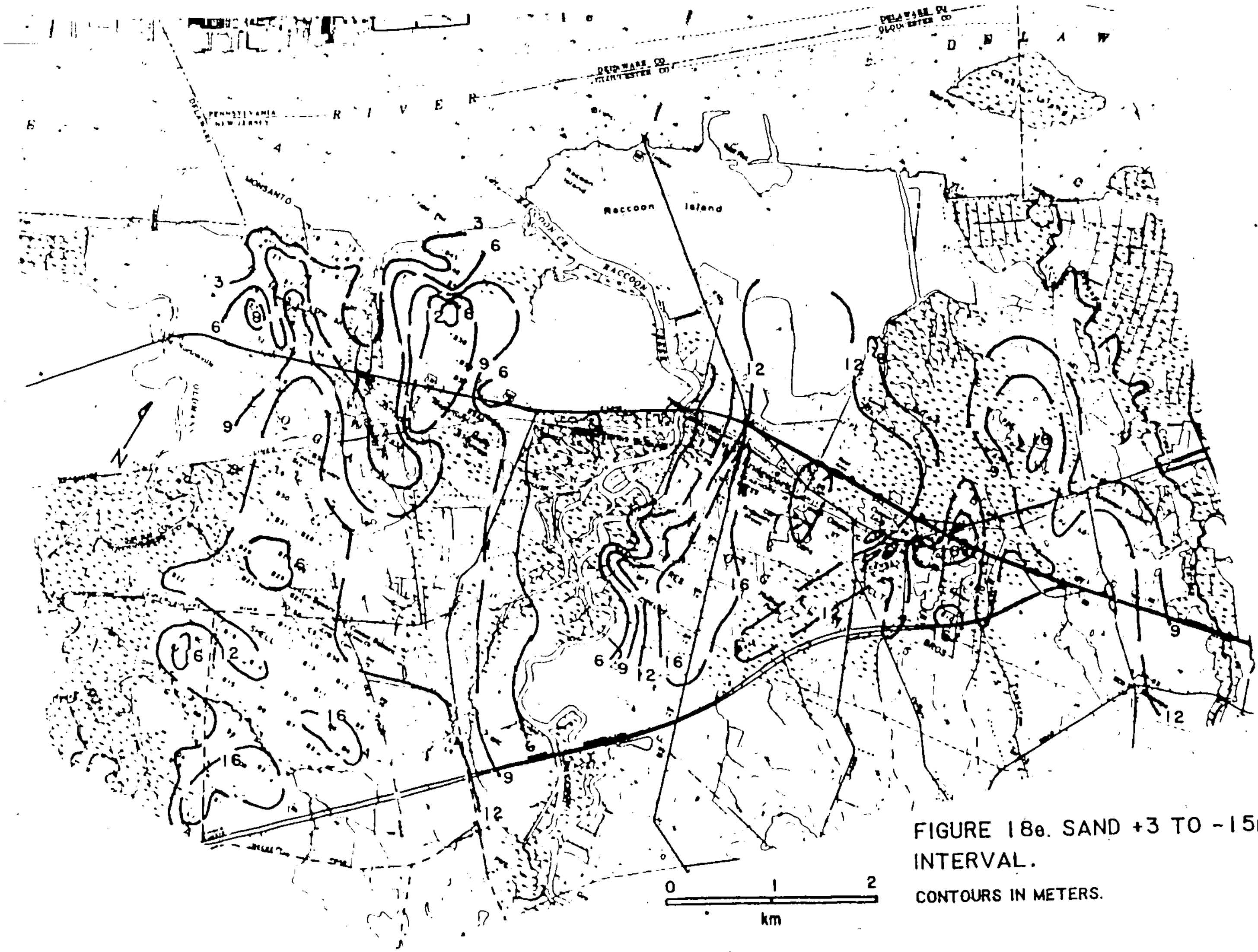


FIGURE 18e. SAND +3 TO -15m, MSL INTERVAL.

CONTOURS IN METERS.

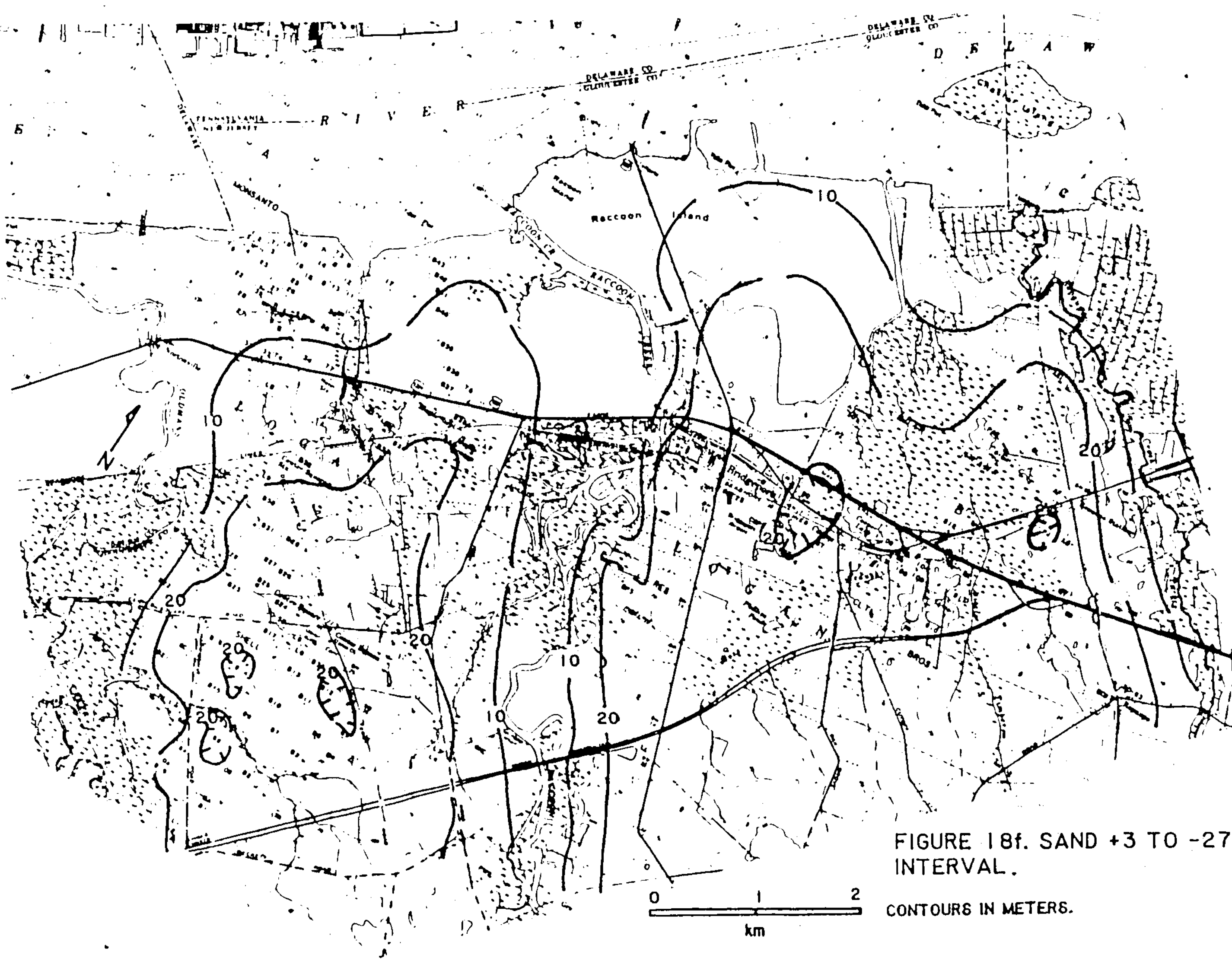


FIGURE 18f. SAND +3 TO -27m,MSL INTERVAL.

CONTOURS IN METERS.

The lithofacies maps of the -6.1 m to -15 m interval (Figures 18c and 18d) are similar to the maps of the +3 m to -6.1 m interval. Lithofacies maps of -6.1 to -15 m interval show that the Quaternary units are primarily clay/silt or organic sediment. The Cretaceous deposits in this interval are primarily composed of sand. Sand lithofacies patterns indicate that sand bodies become thicker and more widespread upsection. Clay/silt lithofacies patterns indicate that clay/silt bodies are discontinuous over the area.

Lithofacies maps of the +3 m to -27 m and the +3 to -15 m intervals (Figures 18e, 18f, and 18g) show that the Cretaceous deposits in these intervals are primarily composed of sand. The fine-grained nature of the Quaternary units is also evident in these maps. Sand lithofacies patterns indicate that sand bodies become thicker and more widespread both downdip and upsection.

5.1.4 Depositional Environment and Subsurface Models

a. Cretaceous section

Evidence of a fluvial depositional environment was observed in outcrops, split spoon samples, and geophysical well logs. Both lateral and vertical accretion deposits, as defined by Cant (1982), are present. Deposits that are predominately sand are lateral accretion deposits (channel and channel-point bar). Predominately clay/silt deposits are vertical accretion deposits (abandoned channel fill and overbank).

The specific depositional environments were inferred from well log analyses, outcrop observations, and comparisons with photographs and descriptions of other modern and ancient fluvial deposits. The lithologic character and the position of a small interval within a larger vertical sequence are the primary criteria used.

Most deposits of organic-poor, thinly laminated (mm scale), clay and silt/sand are probably top of channel/point bar, bank, or near channel overbank deposits. Thick (>2 m), organic-poor, sequences of clay (with minor sand interbeds) are probably overbank (floodplain) deposits. Those clays intermixed with sand and gravel and showing soft sediment deformation features are interpreted to be bank deposits which were incorporated into the channels during channel migration (cut-bank deposits). The isolated, plug-like, organic-poor beds appear also to be cut-bank deposits. Organic rich beds are probably channel fill and/or swamp deposits.

Organic-rich channel fill deposits are not common in the study area. This suggests either that channel migration did not allow these deposits to be preserved, or that the type of fluvial environment present did not lead to the creation of classic oxbow lakes. Significant intraformational erosion, common in this type of depositional environment, may have removed many of the organic-rich channel fill deposits that were present in this area.

Alternatively, the organic-rich facies may have been more common during deposition. Diagenetic reactions could have oxidized the organic matter. The ubiquitous iron oxide concretions and staining may be all that remains of the original organic matter and sulfide minerals. Significant intrastratal solution of the Potomac Group has been proposed by Groot (1955) and Force and Moncure

(1976); and, in all likelihood, both intraformational erosion and diagenetic reactions are responsible for the present distribution of the organic-rich facies.

The study area is located just to the south of a system of basement troughs associated with the ancestral Schuykill River (Farlekas et al., 1976). They report that these troughs are filled with highly permeable sand and gravel. The axis of one of the smaller troughs, informally called the Airport Trough, trends toward the study area. This suggests that a large channel of the ancestral Schuykill fluvial system was a major depositional force in the study area at some point in time.

Lithofacies patterns indicate non-constant depositional conditions in the area during the Cretaceous. The increased thickness of sand bodies in younger and downdip parts of the Cretaceous section suggest that stream competence may have been temporally variable. The distribution and size of clay/silt bodies seen in cross-sections also indicate non-constant depositional conditions. Possibly, the streams alternated between small straight (tributaries) types to larger braided or meandering types. This temporally variable behavior could be related to climatic variation (Blatt et al., 1980). The distribution and size of clay/silt bodies could also be explained by a variable stream gradient caused by episodic uplift(s) of the basement, or a change of drainage patterns within the basin. For example, basement structural activity could have caused the periodic switching of the ancestral Schuykill River from the main channel system to the Airport channel system during deposition of the thicker sand bodies.

b. Quaternary section

Results of heavy mineral and lithologic log analyses, field observations, and previous work indicate that at least three different facies are associated with the Quaternary deposits of the Bridgeport area. They are fluvial, estuarine, and eolian facies.

The distribution of Quaternary upland sands in channel shaped features and the associated lithologic types (poorly sorted, medium to coarse sand, and minor clay interbeds) indicate that these deposits had a fluvial origin. Field relationships support the interpretation that the upland sands belong either to the Spring Lake or Van Sciver Lake beds and were deposited during a Sangamon high sea level stand, as suggested by Owens and Minard (1979). This interpretation is partly based on the assumption that samples 102-35 and 104-35 are of Quaternary age.

Apparently, the environmental conditions existing during deposition of the upland 'channel' sands were different from present conditions. The character of these deposits indicates a higher energy fluvial environment. The mineralogy indicates a Piedmont metamorphic (?Potomac-Raritan-Magothy) source rock. These two facts suggest that the ancestral Delaware River may have been the depositional agent. Possibly, activity of basement structures also influenced the Quaternary depositional history.

The thick accumulations of peat and clay/silt-rich sediment beneath modern streams and swamps appear to be estuarine or marsh-fill deposits. This indicates that modern streams and swamps are superimposed on Pleistocene drainage and that Pleistocene erosion cut deeply into pre-existing deposits (as suggested by Kraft, 1969; and Owens et al., 1974). The age(s) of these materials can not be determined from the available data. It seems reasonable that units that correlate with the Sangamon through Wisconsinan age units, which are recognized in New Jersey and the Delmarva Penninsula, were also deposited in the Bridgeport area.

Salisbury and Knapp (1917) and Owens and Minard (1979) suggest that the Delaware River and its tributaries were the major erosional/depositional agents operating during the Quaternary. The base level of local streams would grade to that of the Delaware River in response to changing sea level. The area of facies change from fluvial to estuarine or marsh environments would also respond to rising or falling sea levels. However, evidence of this sort of facies change was not found in the study area.

During low sea level stands, channel incision was the dominant process. The thick accumulations of Quaternary sediments under the Delaware River and Raccoon Creek support similar conclusions reached by Johnson (1937) and Owens et al. (1974).

During high sea level stands, channel filling was the dominant process. Results indicate that estuarine or marsh environments were the most common. Present conditions in the study area provide a useful model for Quaternary environments. Raccoon and Oldmans

Creeks have anastomosing, migrating channels which cut through tidal flats and marshes (see Figure 8).

Raccoon Creek, at one time, may well have discharged through the present day Maple Swamp-Birch Creek area, and the extensive wetlands area around the mouth of Repaupo Creek suggests that Repaupo Creek has shifted positions in this way also. If sea level were only 3 to 6 m higher, channels would be able to shift course over a large part of the study area.

5.2 HYDROGEOLOGY

5.2.1 Hydrogeologic Framework

The lower and middle aquifers of the Kprm aquifer system are within the study area (Figure 12 through 15). Part of the upper aquifer may be present in the extreme southern part of the study area (Figures 5 and 13).

a. Cretaceous section

As a result of the depositional environment, the Kprm is a heterogeneous (stratified), anisotropic aquifer. As would be expected, coarse grained (sand and gravel) channel deposits function as aquifers, and fine grained (silt and clay) overbank and channel fill deposits function as aquitards. The distribution of aquifers and aquitards are shown in cross sections and lithofacies maps (Figures 12 through 18). The aquitard between the lower and middle aquifers appears to pinch out near the river and the distinction between the lower and middle aquifers is lost.

Thick, possibly multi-story sand bodies probably are the main conduits for vertical ground-water flow. Lithofacies maps show that sand bodies become thicker and more widespread downdip as the Coastal Plain section thickens. Geraghty and Miller, Inc. (1972) report that the transmissivity of the shallow artesian zone also increases in the downdip direction. In general, the Cretaceous section contains more sand than clay. In many locations, the interval from 3 m to -27 m MSL contains over 25 m of sand.

Cross sections (Figures 12 through 15) show that the aquifers are dipping to the Southeast. This is due to the regional dip of the Cretaceous section. Presumably, the individual sand beds which comprise the aquifer also dip to the Southeast. Freeze and Cherry (1979) suggest that the maximum hydraulic conductivity of unconsolidated fluvial deposits is oriented parallel to the direction of flow at the time of deposition. If this is the case, the maximum hydraulic conductivity of the aquifer is dipping to the Southeast.

All data indicate that aquitards will not stop the flow of water between different water bearing zones of the aquifer system. Lithofacies maps and cross sections indicate that aquitards are not evenly distributed, and with the exception of the area near the Delaware River they are usually discontinuous (see Figures 12 through 15). Near the river, the aquitard includes deposits of Quaternary age. Pump test results from wells completed in the middle aquifer (shallow artesian zone), in locations away from the Delaware River, indicate that the overlying confining unit is leaky or locally discontinuous (Geraghty and Miller, Inc. 1971; 1972; 1981; NUS, Inc., 1984). The aquitards are discontinuous as a result of the Cretaceous depositional environment and Quaternary erosion. Pump test data on the confining characteristics of the aquitard separating the lower and middle aquifers in the study area is lacking. However, it appears that all of the aquitards only slow the flow of water between the different water-bearing zones, by temporary storage, and/or by making flow paths longer and more tortuous.

Farlekas et al. (1976) suggest that aquitard storage may be significant. If this is the case, the calculated vertical permeabilities (Table 4) and leakage rates are too large, and horizontal flow is even greater than suspected. However, the Bureau of Reclamation (1977) and Freeze and Cherry (1979) suggest that the distinction between aquitard storage and leaky confining layers commonly can not be made from pump test data. When one considers that the aquitards are discontinuous, and from the shapes of time-drawdown and distance-drawdown curves, it appears that aquitard storage is not as significant as Farlekas et al. (1976) suggest and vertical leakage plays a more dominant role in the area.

b. Quaternary section

Laboratory permeability tests indicate that the fine grained deposits (silt, clay, and organic) function as aquitards. They also store water for release to aquifers and surface water bodies.

Coarse grained upland deposits (sand and gravel) function as aquifers. They apparently have a discontinuous distribution so they are not important water-bearing units. However, they are hydraulically connected to the Kprm aquifer system. Permeable Quaternary deposits serve as conduits for vertical flow where they cut through Cretaceous aquitards.

In summary, the Quaternary deposits add a degree of heterogeneity to the aquifer, by both their distribution and composition.

c. Bedrock

The Wissahickon Group is not an important water-bearing unit compared to the overlying Kprm aquifer system (Hardt and Hilton, 1969). It functions as the impermeable base to the overlying aquifer (Farlekas et al., 1976).

5.2.2 Water Budget

The water budget for the study area is largely based on the data and analyses of Vowinkel and Foster (1981), and data from water year 1982 (Bauersfeld et al., 1983). The study area is included in Vowinkel and Foster's drainage segment 12. Average annual runoff values were estimated from discharge records of Raccoon Creek (near Sweedesboro, location 8) and by comparison with nearby streamflow gaging stations with similar basin characteristics. Note that this approach does not separate direct runoff from ground-water runoff (baseflow). Water loss (evapotranspiration) was then calculated by assuming no long term change in storage and the equation:

$$\text{Water Loss} = \text{Precipitation} - \text{Runoff} \quad (1)$$

The available data, presented in Table 6, cannot justify a more complex water budget equation. A more complex water budget equation would be necessary for a detailed hydrologic study.

Table 6
Water Budget
Average Annual Values (m/year)

	A	B	C	D	E
Precipitation	1.10	1.04	1.13	1.12	1.02-1.22
Runoff	0.53	0.36	0.63	0.56	0.51-0.71
Water Loss	0.57	0.48	0.74	0.56	0.51-0.71

A. Vowinkel and Foster (1981), segment 12 B. Coastal Plain minimum values C. Coastal Plain maximum values D. Hardt and Hilton (1969) E. Linsley et al. (1975)

The calculated water loss (for segment 12) is 0.038 m less than the Coastal Plain average. Since ground-water levels in the study area usually are within 1.5 to 3 m of land surface and swamps cover a large percentage of the area, an average evapotranspiration rate for the study area may be closer to the Coastal Plain maximum (column c) than that shown for segment 12.

The runoff values compare well with the estimates of Hardt and Hilton (1969) and Linsley et al. (1975; c.f. Langbein et al., 1949), but the streamflow data was collected in the outcrop area of the Mount Laurel and Wenonah Formations. Therefore, it's applicability to the study area is questionable. Additionally, a higher water loss rate and ground water pumping from the Kprm aquifer system, both within and outside of the study area, probably reduces the amount of ground water runoff in the outcrop area (Farlekas et al., 1976). Loss of water to the regional flow system is discussed in later sections.

5.2.3 Surface Hydrology

The study area includes the entire Maple Swamp drainage basin and the lower reaches of the Raccoon Creek, Oldmans Creek, and Repaupo Creek basins (Vowinkel and Foster, 1981). Several sub-basins: the Little Timber Creek, Moss Branch, and Cedar Swamp are located within the Repaupo Creek basin (see Figure 8). The study area is bounded on the north, east, and west by the Delaware River, Repaupo Creek, and Oldmans Creek respectively. The southern boundary is not as well defined. It is arbitrarily placed at the southern boundary of the lower aquifer outcrop area.

Average stream gradients, estimated from topographic maps, range from approximately 2×10^{-4} for larger streams (third and fourth order) to approximately 6×10^{-4} for smaller streams (first and second order). The effect of the Delaware River stage on stream gradients is uncertain. Field observations indicate that gradients decrease during periods of high water in the Delaware River. River stage data are presented in Appendix 1.

Surface water hydrology varies considerably with climatic and seasonal cycles. Figure A2 (Appendix 1) shows the variation in total monthly discharge for Raccoon Creek (near Sweedesboro, location 8) and total monthly precipitation at the Marcus Hook weather station (location 7), for water year 1982. This figure illustrates the decrease in the proportion of runoff during the growing season (due to evapotranspiration). Field observations from October 1981 to March 1984 indicate that Little Timber Creek and Moss Branch behave in a similar fashion. Visible current in these water bodies was present only during late fall to early spring, and temporarily after some intense summer storms. Stagnant water conditions were common during summer months. This decreased stream discharge during the growing season is a common phenomenon (Walton, 1970).

Review of older aerial photographs and maps indicate that dredge spoil disposal in Cedar Swamp has significantly changed drainage patterns several times within the past 30 years. Dredge spoils also have been used to fill the marshes around the mouths of Raccoon, Birch, and Oldmans Creeks (Markley, 1959; Woodward and Morehouse, 1972; field observations). The effects of this practice on surface hydrology have not been determined, but are probably significant.

5.2.4 Ground-Water Hydrology

Toth (1963) suggests that three types of flow systems; local, intermediate, and regional, may exist in a drainage basin. Based on Toth's work, Fetter (1980) and Freeze and Cherry (1979) suggest that the size and number of flow systems are dependent on water table relief and basin geometry, topography, and geology. The boundaries of the flow systems are in a state of dynamic equilibrium, dependent on the same factors. Toth (1963) found that stagnant or near stagnant bodies of ground water exist where flow systems branch or intersect.

In the following sections, ground-water flow is described in the context of flow systems. Based on this approach and all available data, it appears that a complex flow system; with local, intermediate, and regional components exists within the study area. The relative importance (and size) of a flow system is described in terms of the complex relationships between recharge, discharge, and storage. In turn, recharge, discharge, and storage are functions of climatic, hydrogeologic, and biologic factors.

a. Head distribution

Potentiometric surface maps of the various water-bearing zones in the Kprm aquifer system are shown in Figure 7 and in Figures A5.1 through A5.9 (Appendix 5). Table 7 presents the range of head values observed at several sites in the study area. Well construction details for the wells which are used in the water level study are included in Appendix 5. Construction details were obtained from reports of consultants and from well records filed with DWR. Screened intervals of selected wells are shown in the cross sections (Figures 12 through 15). The accuracy of water level measurements is discussed below.

Table 7
Range of Head Values (m,MSL)

Site	Water Table	Middle Aquifer	Lower Aquifer	Remarks
CLTL-BROS	0.6 - 1.8	0.02 - 1.8	-	1981-1984 a,b,c
RES	0.6 - 2.4	0.02 - 2.1	-	1978-1983 d,f,g
Shell-Pureland	0.9 - 4.2	-0.9 - -1.5	-0.3 - -1.5	1972-1983 e,f
Monsanto	0.6 - 2.4	-3.0 - -6.8	-	1970-1983 f,g

Sources: a. Field observations b. ERM c. NUS 1984 d. Geraghty and Miller, Inc. e. Geraghty and Miller, Inc. 1971; 1972 f. Walker 1983 g. Files, DWR

The potentiometric surface maps (Appendix 5) indicate that local flow direction and magnitude may vary with time. In the Bridgeport Rental and Oil Services (BROS)-Chemical Leaman Tank Lines (CLTL) area, flow directions have varied nearly 90 degrees. Flow direction sometimes varies between different levels in the aquifer (see Appendix 5). At RES, BROS, and CLTL, vertical gradients also vary in direction and magnitude. Vertical gradient data is tabulated in Appendix 5.

Freeze and Cherry (1979) suggest that the factors listed in Table 8 will cause water level fluctuations. All of these factors are operating in the study area.

Table 8
Sources of Water Level Fluctuations

Source	Time	Space
Ground Water-Recharge	Climatic, Seasonal	unconfined aquifer geologic control
Evapotranspiration	Climatic, seasonal, diurnal	unconfined aquifer, topography, vegetation
Bank and Depression storage	Climatic seasonal	unconfined aquifer, topography
Barometric Pressure	Climatic	confined, unconfined aquifers
Tidal Cycles	Diurnal	unconfined, confined aquifers
Pumping wells	Climatic, seasonal, long term	well locations

Most water level measurements completed in the study area have been done with steel or electric tape. These measurements give a 'snapshot' type view of water levels. The accuracy of this type of measurement may be adversely affected by several factors. For example, water levels in wells tapping confined aquifers are affected by changes in barometric pressure (Freeze and Cherry, 1979). Geraghty and Miller, Inc. (1972) calculated barometric efficiencies (i.e., the ratio of the water level change to the barometric pressure change multiplied by 100) of 10 to 20 percent for wells completed in the shallow artesian aquifer at the Shell site. Possibly, some of the observed water level variability can be explained by this phenomenon. The effects of diurnal tidal and evapotranspiration cycles may also be overlooked with the 'snapshot'

Table 8
Sources of Water Level Fluctuations

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Bank and Depression storage	Climatic, seasonal	unconfined aquifer, topography
Barometric Pressure	Climatic	confined, unconfined aquifers
Tidal Cycles	Diurnal	unconfined, confined aquifers
Pumping wells	Climatic, seasonal, long term	well locations

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water level measurement. Continuous water level recorders should be used in conjunction with barometer and tide gage readings to more completely understand the effects of these factors at any given site.

b. Recharge

Recharge of the water table is partly dependent on the infiltration characteristics of surface materials. However, the data needed to calculate site-specific infiltration characteristics are not available. An estimate can be made from other observations. Aerial photographs, soils maps, and topographic maps show that land surface is largely undeveloped farm and forest, slopes are less than 5 percent, and soils are sandy. This suggests that little or no precipitation reaches streams as surface runoff. Field observations also support this. However, direct runoff from roads and developed areas may be locally important.

Soils maps (Markley, 1959), test pits, and boring logs indicate that the infiltration characteristics of surface materials are spatially variable. Recharge of the water table by precipitation appears therefore, to be spatially variable.

Recharge is partly dependent on climatic factors. Based on a 30 year average, Farlekas et al. (1976) report that precipitation is fairly evenly distributed throughout the year, although the spring and fall months are usually wetter. Freeze and Cherry (1979) and Fetter (1980) suggest that most recharge occurs during spring through fall when the ground is not frozen. Recharge generally decreases from spring-time rates during summer and early fall when the evapotranspiration rate and soil moisture deficits are highest (Walton, 1970). Long term fluctuations, such as the drought of 1981, also influence recharge. Well hydrographs from RES and the nearby area (locations, Figures 1 and 8) show the seasonal and long term variations in recharge (see Appendix 5). Long period well hydrographs appear to show that most recharge occurs during November through April.

c. Discharge

The Kprm aquifer system discharges water by runoff, evapotranspiration, and pumping wells. Some of the water discharged to wells is recycled back to the aquifer through septic systems, irrigation, and industrial wastewater disposal fields and lagoons. The remainder is discharged directly to streams, and presumably lost from the aquifer. The amount of water in this second category was estimated from the Monsanto and Pureland Water Company pumping records, which are on file at DWR. Most, if not all, of the water pumped by these companies is discharged, via treatment plants, to the Delaware River (DWR, files).

Regional potentiometric surface maps show that Logan Township is located in one of the few areas where the potentiometric surface is greater than MSL. This indicates that water also discharges from the study area to the regional flow system.

d. Local versus regional flow

Head and gradient data indicate that a complex flow system is present. The boundaries between local and more regional flow systems are dependent on aquifer characteristics, climatic trends, and pumping history. Therefore, the relative volume of aquifer belonging to a given flow system is variable in time and space. The volumes are dependent on the relative 'strength' of the driving mechanisms of each flow system. Hydraulic gradients are a measure of the strength of these driving mechanisms.

Luzier (1980) and Farlekas et al. (1976) conclude that pumping wells have caused the decline in the regional potentiometric surface. The regional flow system is partly driven by the gradients created by pumping wells located outside of the study area. Regional flow is also partly driven by recharge in the aquifer outcrop area. Regional gradients in the lower and middle aquifers, calculated from Walker's (1983) maps, are in the range of 7×10^{-4} to 1×10^{-3}.

In the study area, local flow systems are driven by pumping wells, evapotranspiration, topography, and infiltrating precipitation. Horizontal and vertical gradients are in the range of 5×10^{-5} to 5×10^{-3}, and 9×10^{-4} to 3×10^{-1}, respectively.

Based on data from 1972 to 1983, the potentiometric surface of the lower artesian zone (lower aquifer) has been below MSL (Geraghty and Miller, Inc., 1971; 1972; Walker, 1983). This indicates that the lower artesian zone will not discharge to surface water and therefore must be part of the regional flow system. Based on head data from well nests DP1-R, DP3-U (RES); S2, S11 (BROS); and, CL2-DW2 (CLTL), the shallow artesian zone (middle aquifer) may sometimes be part of the regional flow system. Surface water head data is not sufficient to determine if, or how often the shallow artesian zone has the potential to discharge to surface water bodies.

Those parts of the aquifer which are not included in the regional flow system are parts of the local flow systems. Local flow system boundaries include all surface water bodies, topographic drainage divides, and pumping wells.

Regional potentiometric surface maps from Walker (1983) show that Logan Township is one of the few areas in the lower Delaware River Valley where heads in the middle aquifer are above MSL. This indicates that ground water in the study area is not derived from underflow from outside areas. Therefore, some of the available precipitation must be lost to the regional flow system because there are no barriers to stop the flow of water out of the study area.

Darcy's Law

$$Q = KiA \quad (2), \quad \text{where}$$

i = gradients measured from Walker's (1983) maps,

K = a representative range of hydraulic conductivities (K), and

A = areas estimated from cross sections and maps;

is used to estimate the rate of water loss (Q) to the regional flow system per 30.5 m thickness of aquifer. The middle aquifer ranges from a minimum of 15 m to as much as 45 m thick in some places. Available well logs indicate that the lower aquifer is up to 30.5 m thick also. Therefore, these estimates may be less than the actual flow rate by up to 50 percent.

K range = 3.0×10^{-5} to 4.6×10^{-3} m/sec, average 4.6×10^{-4} (Hardt and Hilton, 1969)

i range = 7×10^{-4} to 1×10^{-3}, estimated average 9×10^{-4}

A = 1.29×10^{4} m x 30.5m = 3.93×10^{5} m^2

Q = 8.26×10^{-3} to 1.81×10^{-1} m^3/sec, average 1.63×10^{-1}

The ratio of loss to the regional flow system to available precipitation is estimated from the calculated loss rate and the average annual recharge rate. The average annual recharge rate is estimated from the equation:

R = (Pa x Ar)-P (3), where

Pa = available precipitation, average annual runoff 0.36-0.74m

Ar = land area available for recharge (1.93×10^{7} m^2)

P = Pumping rate (9.64×10^{-2} m^3/sec)

1.23×10^{-1} to 3.56×10^{-1} m^3/sec

Assuming that the average loss rate is an accurate estimate, the loss to the regional flow system exceeds the minimum annual average recharge, and is nearly 45 percent of the maximum annual recharge rate. An unknown amount is lost to ground-water runoff (baseflow). Ground-water runoff occurs when the aquifer can not transmit all recharge to pumping wells or the regional flow system, and the aquifer storage capacity is exceeded. If runoff is significant or available precipitation is less, then the percentage lost may reach up to 40 percent.

e. Transfer between local and regional flow systems

The potential exists for water to flow between the local and regional flow systems. Local and regional horizontal gradients are on the same order of magnitude (see Appendix 5). Local vertical gradients between the water table (local flow system) and deeper (>15 m) parts of the aquifer generally are hundreds to thousands of times greater than the horizontal gradients (see Appendix 5). Thick, possibly multi-story sand bodies commonly connect the water table with deeper parts of the aquifer. The maximum hydraulic conductivity of the Cretaceous deposits is dipping to the Southeast in the direction of the regional gradient.

On the basis of regional potentiometric surface maps, Logan Township appears to be a regional recharge area. Precipitation which is not lost to evapotranspiration, runoff, and/or pumping wells flows to deeper or downdip parts of the aquifer system (see Figure 19).

5.2.5 Surface Water-Ground Water Relationships

Site access problems prohibited collection of synoptic surface water and ground water measurements. However, the ranges of possible behavior of swamps, streams, lakes, and gravel pits and their influence on local hydrology can be inferred.

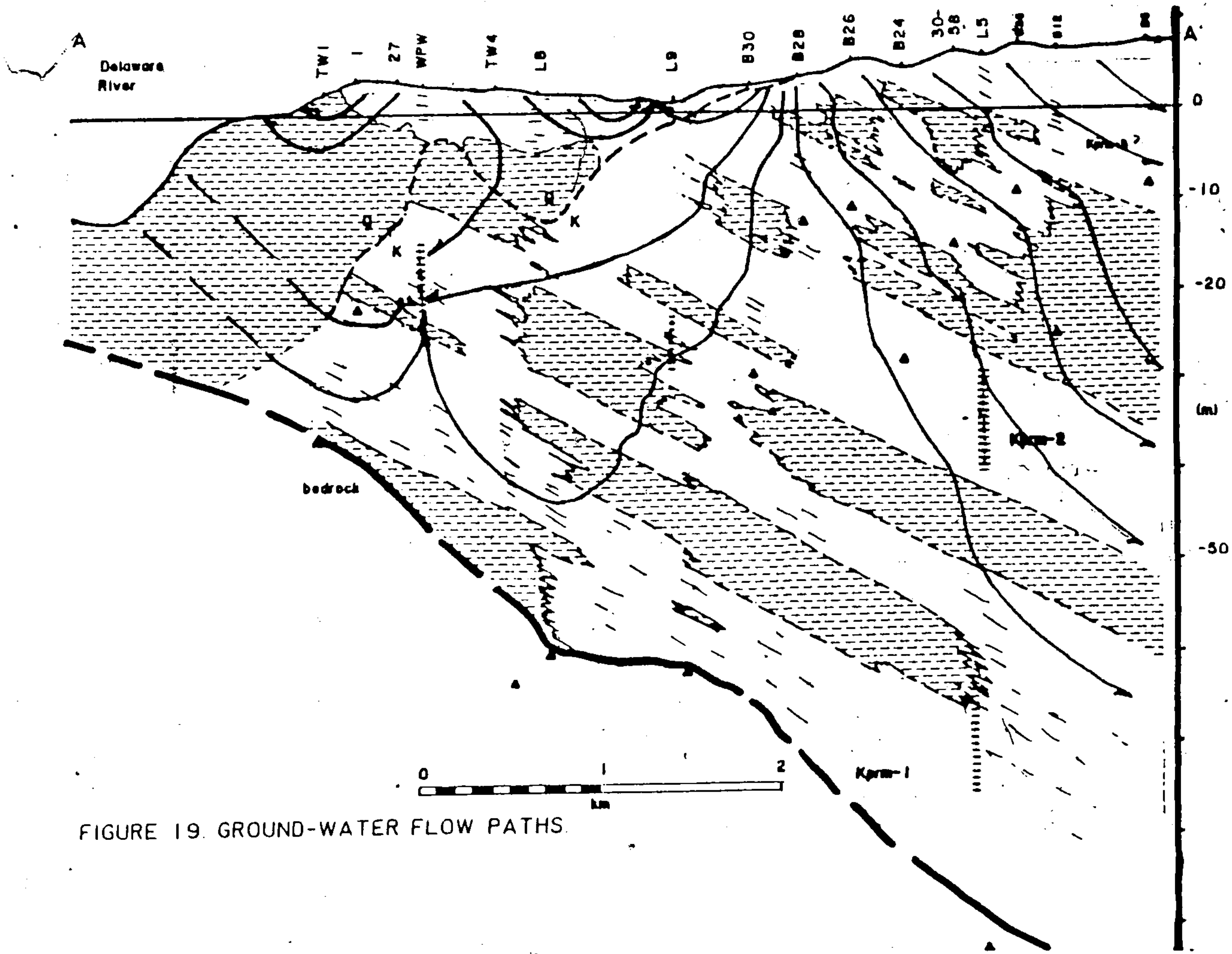

FIGURE 19. GROUND-WATER FLOW PATHS

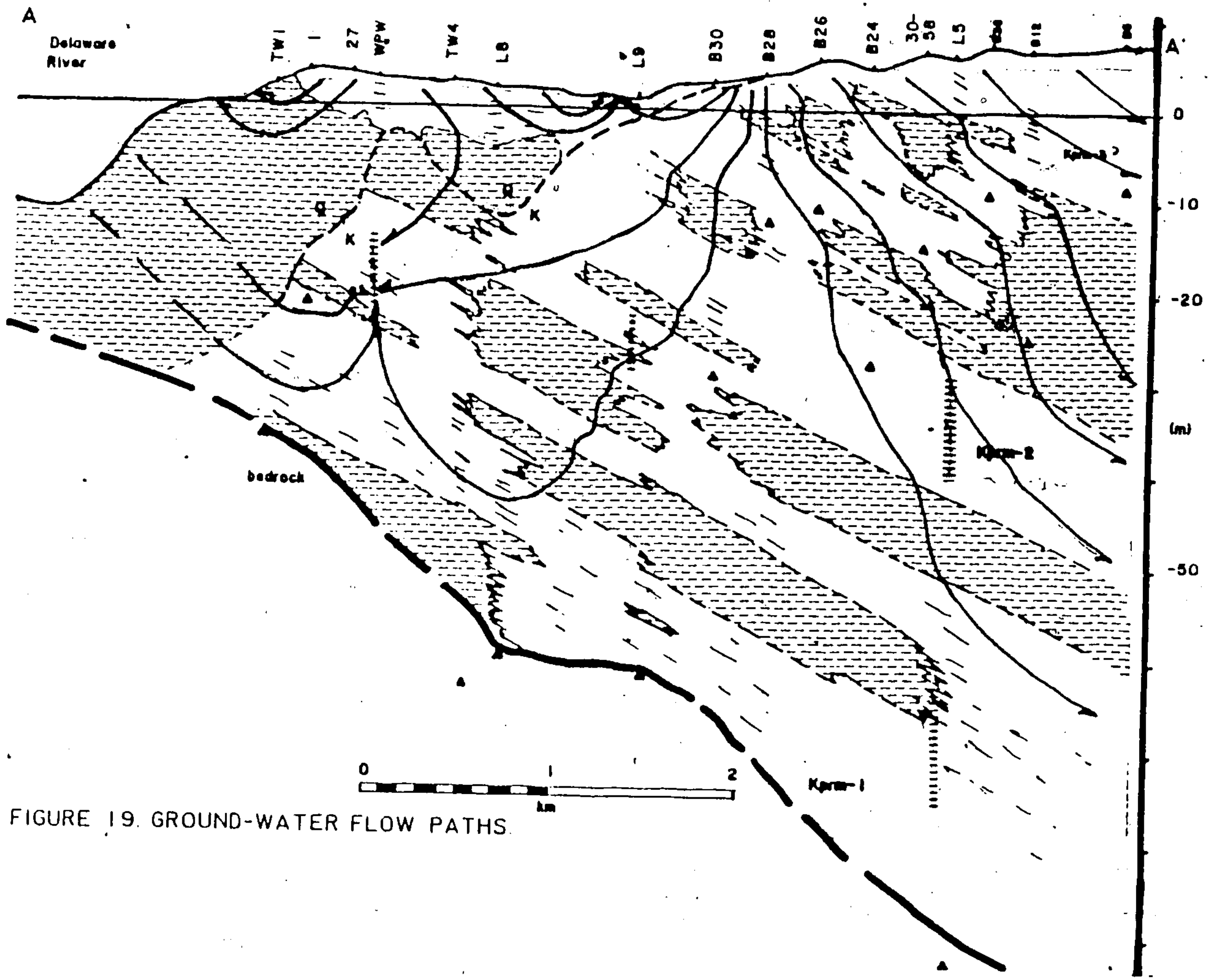

FIGURE 19. GROUND-WATER FLOW PATHS

a. Swamp behavior

Swamps contain many elements which should cause ground-water levels to fluctuate. Swamps in this area are classified into two basic types: those adjacent to tidal streams; and, those not adjacent to tidal streams.

Field observations indicate that swampy areas bordering tidal streams function as floodplains or tidal flats.

Swamps not adjacent to tidal areas include Moss ~~Branch and~~ Little Timber Creek Swamps and parts of Cedar Swamp. These swamps are poorly drained, topographically low areas. They are heavily vegetated by deciduous trees and shrubs. Shallow (<3 m) subsurface materials are highly variable, although peat and clay/silt apparently predominate. The water table is usually not more than 15 cm bls year round. Water ponds and flows on the surface in response to precipitation during November through April, and after some intense summer storms. Swamp outlets usually have visible current only during these months. During summer months, surface water in swamps is generally stagnant. However, field observations show that water temperature is cool (14-18 degrees C), indicating a discharge from the ground-water reservoir.

The elevation of water in Moss Branch Swamp usually varies (seasonally) from 0.8 to 1.4 m MSL (field observation). Higher elevations may exist when the Delaware River is at a higher stage. Local residents have stated that Cedar Swamp Road (elevation > 2.2 m) is periodically covered by floodwaters. The duration of high water conditions is not well known. Field observations indicate that they may exist for periods greater than 7 days.

LANDSAT snowfall scans show no accumulation of snow in the swamps when uplands are snow-covered. False color, infrared LANDSAT summertime scans show the swamps are cooler than surrounding upland areas.

Field observations and remote sensing data indicate that swamp hydrology is complex. Under most conditions, swamps are ground-water discharge areas. The water is lost by evapotranspiration and by runoff via the small streams. Evapotranspiration is extremely important during the growing season, replacing streamflow (runoff) as the dominant form of ground-water discharge. No estimates or measurements of the evapotranspiration rate were made. Runoff is significant during fall through spring and temporarily after some intense summer storms. It is composed almost entirely of ground-water runoff.

Swamps may focus ground-water discharge because of subsurface conditions. The low permeability Quaternary marsh and bog deposits which underlie the swamps can not transmit as much water as the aquifer. Flow will be deflected up to the surface or to other more permeable units to make up for this. This phenomenon is illustrated in Freeze and Cherry (1979; Figure 6.4).

Field observations indicate that swamps are sites of depression storage. Low stream gradients, dense vegetation, and low permeability subsurface materials cause storm runoff to be temporarily stored in the swamps. Water may be stored for hours to weeks depending on climatic conditions, the particular storm, river stage, and ground-water levels.

When water is in storage, swamps may act as temporary ground water-recharge areas. This may be classified as depression-focused recharge. Recharge can occur only if surface heads exceed ground water heads, such as might be the case after an intense storm or prolonged wet period (see Figures 20b and 20c). An important aspect of this phenomenon is that the boundary (stagnation point) between local and more regional flow systems moves up toward land surface. Alternatively, if the swamp can discharge all runoff without increasing surface water elevations, then water table topography would increase and the boundary (stagnation point) between local and regional flow systems would move down into the aquifer (see Figure 20d). Figure 20 illustrates these possibilities for a hypothetical swamp in a homogeneous aquifer. Aquifer inhomogeneities will alter flow paths significantly. Field observations apparently support depression storage and recharge rather than constant head conditions.

b. Lakes and gravel pits

In the study area, sand and gravel is quarried from upland sand deposits. Pits are excavated 3 to 12 m bls, which can be many meters below the water table. Gravel pit excavation has altered natural conditions by converting ground-water recharge areas into areas of ground-water discharge.

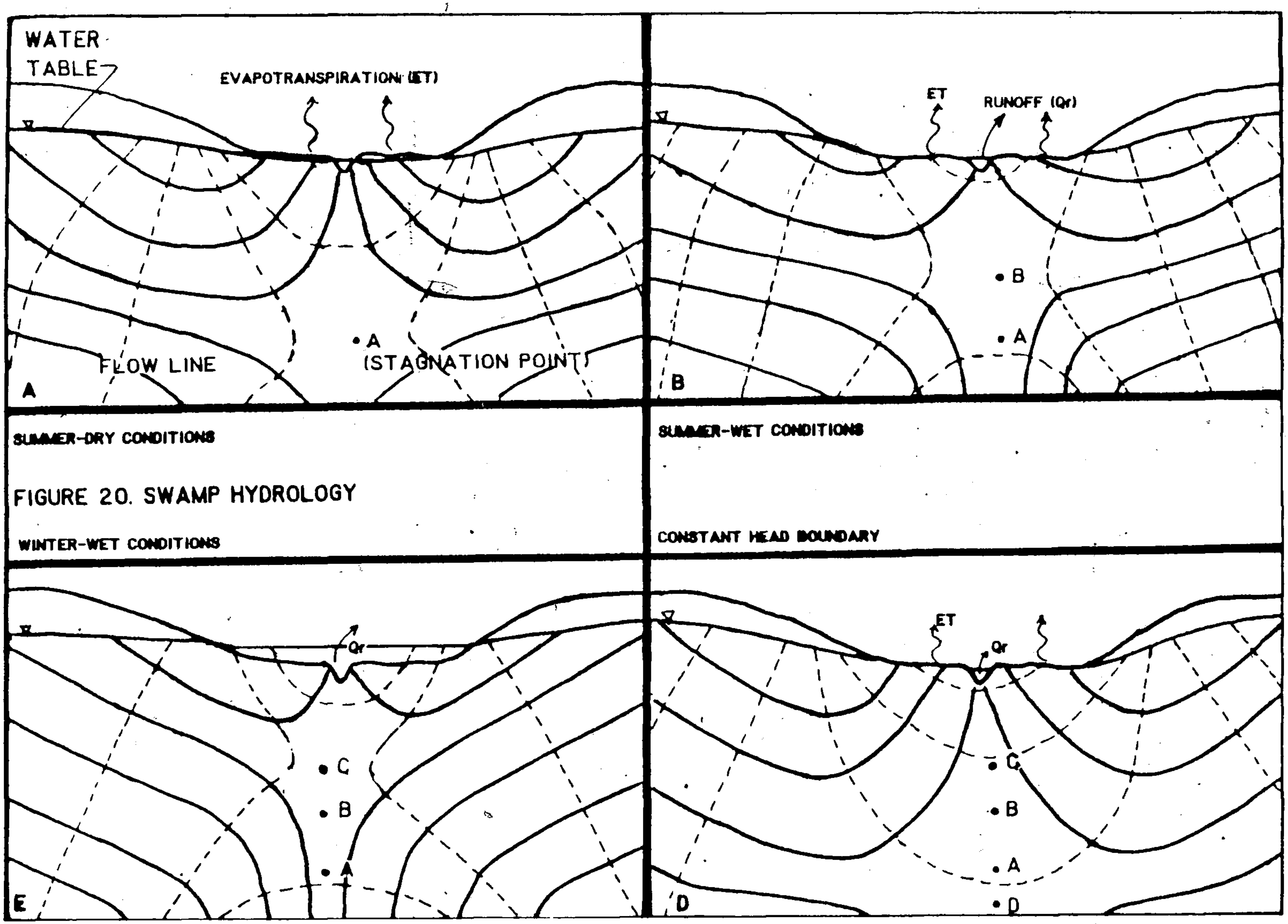

FIGURE 20. SWAMP HYDROLOGY

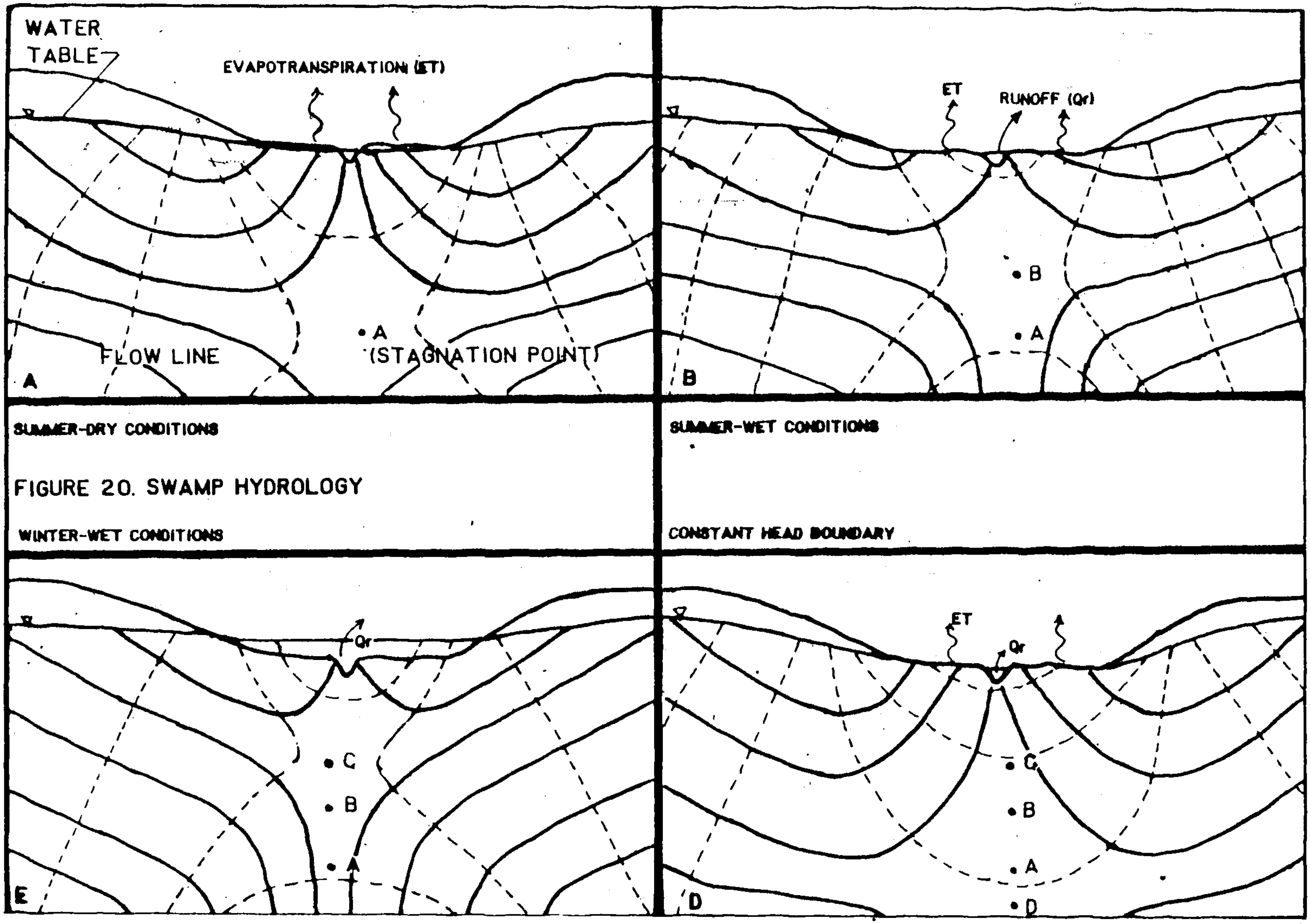

FIGURE 20. SWAMP HYDROLOGY

The location of the stagnation point between the local and regional flow systems is a function of the evaporation rate, the composition of the pit bottom, and location of the lake or pit with respect to recharge and discharge boundaries. The stagnation point will move down in the aquifer during warmer periods when evaporation rates are highest, and it will move up in the aquifer during cooler periods and precipitation events. Gravel pits may also function as temporary recharge areas after large precipitation events. Recharge rates would be highest during cooler periods (fall through spring) or during extremely wet periods.

The composition of the pit bottom may limit the amount of water which can be discharged. Clay/silt beds will restrict the flow of water from deeper portions of the aquifer. The depth of excavation in several pits was limited by localized clay/silt beds (field observations). Complex flow patterns beneath these pits are created by the presence of clay/silt beds.

c. Delaware River

The aquifer and the Delaware River and its tributaries are in a state of dynamic equilibrium. The river probably functions as a regional flow boundary because of the width and depth of the channel. The available river stage data suggests that the river may be either a recharge or a discharge boundary. The stage of the Delaware River has a large impact on the hydrology of the study area. River stage data are presented in Appendix 1.

River stage varies in response to tidal and climatic influences. Tidal fluctuations, reported by Geraghty and Miller, Inc. (1972), and estimated from monthly mean low and mean high water data, are approximately 1.6 to 1.9 m (Bauersfeld et al., 1983). Water level data indicate that tidal fluctuations are damped out within 100 to 200 m of tidally affected surface water bodies (BGWM, 1982). However, given the tidal range and the range of heads in the aquifer, it appears that tidal fluctuations cause tidal streams to vary between recharge and discharge boundaries.

Monthly mean river stage varied over 0.3 m during water year 1982 (Bauersfeld et al., 1983). Trends in river stage roughly correlate with climatic trends. Ground-water hydrographs from well nest DP3-U (RES) appear to roughly correlate with climatic trends also, indicating that these longer term fluctuations (climatic or seasonal) influence the entire outcrop area (see Appendix 5). A similar phenomenon is observed on well hydrographs from USGS operated Kprm observation wells (see Appendix 5), indicating that climatic trends influence water levels throughout the aquifer.

5.2.6 Summary

Many interactive factors are responsible for the complex hydrogeologic conditions observed in the study area. Among these are:

1. heterogeneous, anisotropic aquifer;
2. surface water-ground water interactions;
3. climatic variations;
4. gradients caused by pumping wells located within and outside of the study area; and

5. other man induced stresses.

All of the natural factors tend to cause temporally variable gradient directions and magnitudes. Variable gradient directions and magnitudes are an indication of moving flow system boundaries. In the local flow systems, variable gradients slow the flow of water from recharge areas to local discharge areas.

Data are not sufficient to determine the long term relationships between ground water and surface water. However, the data indicate that bodies of surface water may behave either as recharge or discharge boundaries, depending on the conditions existing at any given time. The duration of one type of boundary is dependent on climate, local geology, and the influence of pumping wells.

Pumping wells may or may not produce temporally consistent gradients. Data indicate daily pumping volumes for the larger wells vary only slightly from day to day, and season to season. Records for irrigation wells indicate a strong seasonal and climatic variation in pumping volume.

Pumping wells appear to cause the regional gradient and the larger local gradients. Resultant flow directions are vertically downward and/or downdip. The results of this study suggest that a significant portion of available recharge flows to pumping wells within and outside of the study area. This portion will increase as pumping increases.

5.3 NUMERICAL MODEL

The finite-difference ground-water flow model developed by Trescott (1975) and modified by Trescott and Larson (1976) was used to simulate flow in a multi-layer heterogeneous aquifer such as that encountered in the study area. Input data for the model was based on data collected in Logan Township and the immediate area. Results of the model studies will help illustrate the relationships between local and regional flow systems in this area.

The response of the model to variations of input data was used to help determine which parameters most strongly affect ground-water flow. As with many types of modeling, results are commonly non-unique. For example, increased recharge can be accommodated with little change in head, by allowing more water out of the model.

The finite-difference approximation to the equations of ground-water flow uses an iterative procedure to calculate the potential field. The aquifer to be modeled was discretized into a series of block-centered nodes. Each node was assigned a value for transmissivity (T) or hydraulic conductivity (K) based on available data. T and K values were estimated where site-specific data is unavailable.

In this study, the pseudo-three dimensional flow equation is solved (equation 4, Trescott, 1975). Vertical K (Kv) values are assigned to each node in the input data set. In contrast, the three-dimensional flow model calculates the Kv of each node from horizontal K (Kh) and an assigned anisotropy factor (Trescott and Larson, 1976).

Given the complexity of field conditions and the gaps in the data base, some simplifying assumptions were necessary before the computer model could be used. The major assumptions on which the model is based and the actual aquifer conditions are summarized in Table 9. In this study, flow in a multi-layered cross-section is simulated. Field data show that the ground-water flow field is three-dimensional. The two-dimensional approximation to the flow field is described below.

Table 9
Comparison of Model Assumptions and Aquifer Characteristics

Assumption	Real World Conditions
Two dimensional cross sectional flow	Three dimensional flow field
Heterogenous porous medium	Heterogenous porous medium
Water table conditions in uppermost layer	Water table aquifer present
Steady state or transient finite-difference approximation to flow equations	Aquifer in dynamic equilibrium
Uniform recharge	Uncertain
No evapotranspiration	Evapotranspiration exists, seasonal effects are averaged

The regional flow system, apparently comprising the lower artesian zone and perhaps parts of the upper artesian zone, is transmitting water away from the study area. Regional flow in the model was approximated by constant head nodes (CHNs) which transmit water out of the model. The volume of water leaving the model through these CHNs was compared with estimates based on field data.

Parts of the cross-section trend parallel to sub-parallel to the flow directions in the local flow system. The amount of error introduced by the two-dimensional approximation is unknown. If observed heads and gradients are matched, then the modeled recharge rate may be too small because additional water can be accommodated by flow lines oriented at an angle to the cross section.

a. Boundary conditions and model dimensions

The model approximates flow in a cross section similar to Figure 12. The cross section is oriented nearly parallel to the strike of the Potomac Group. Model dimensions, boundary, and input data are summarized in Table 10 and on Figure 21. In the model, flow was driven by adding water to the top layer with the diffuse recharge option and letting water out through CHNs.

Table 10
Model Dimensions and
Boundary Conditions

Dimensions	
x, dx	9692 m, variable spacing
y, dy	15.4 m
z, dz	normalized to 0.30 m
Boundary Conditions	
Seven Layer	
Constant head	Nodes representing streams, swamps, and end nodes of bottom layer.
No flow	Base of shallow artesian aquifer, and other end nodes.
Eight Layer	
Constant head	Nodes representing streams, swamps, bottom layer, and end nodes of layer 2.
No flow	Base of deep artesian aquifer and other end nodes.

Streams and swamps, the end nodes of layer two, and the bottom layer were treated as CHNs. Two layers of CHNs were assigned to the nodes representing Oldmans, Raccoon, and Repaupo Creeks. The channels of these larger streams are cut down below -1.5 m MSL, corresponding to the second uppermost layer of the model. The elevations of these CHNs were approximated from tidal range values reported by Bauersfeld et al. (1982). The elevations of the CHNs in the bottom layers were inferred from data in Walker (1983).

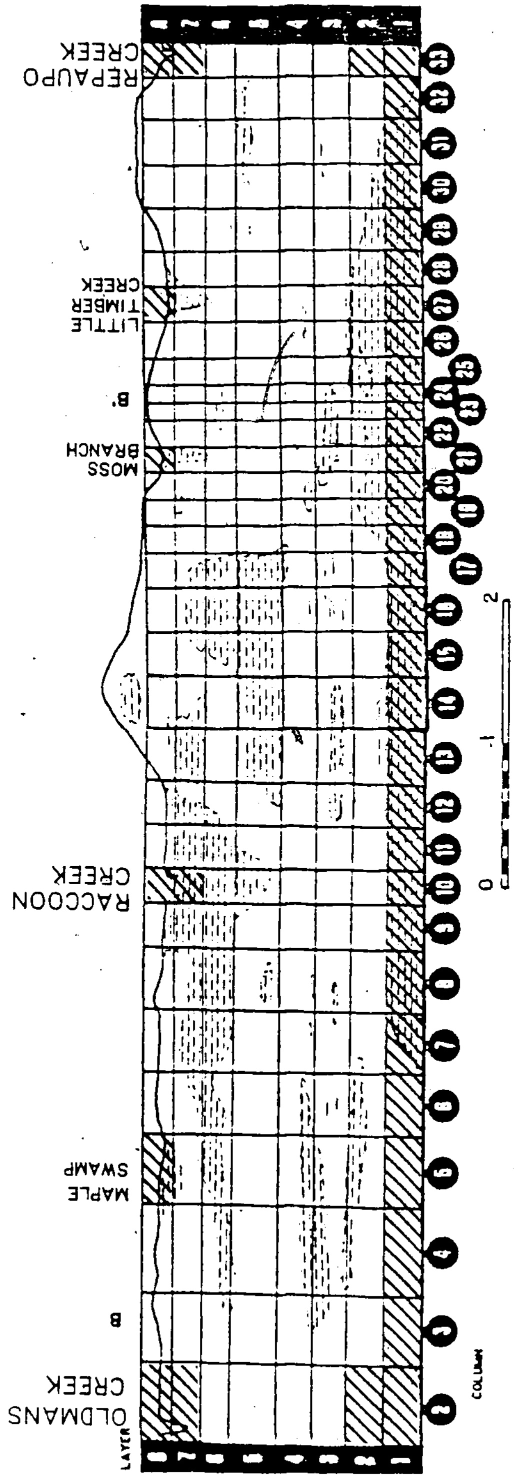

FIGURE 21. NUMERICAL MODEL.

CONSTANT HEAD NODES
AQUIFER
AQUITARD
NO FLOW BOUNDARY

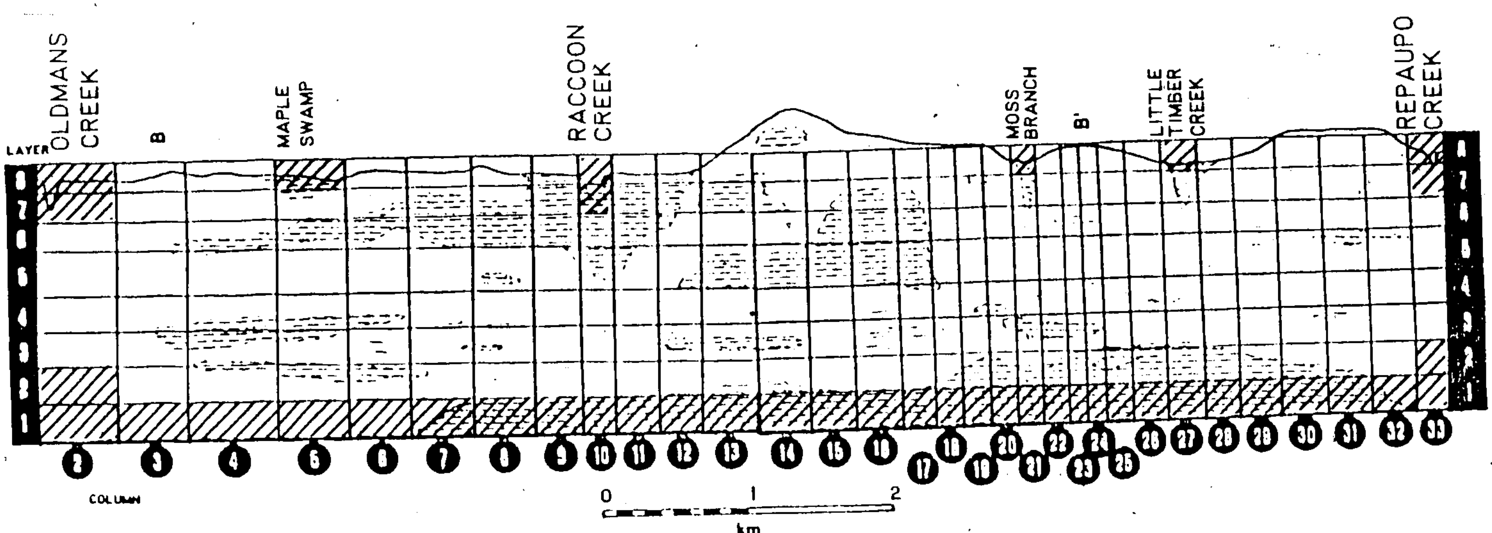

FIGURE 21. NUMERICAL MODEL.

CONSTANT HEAD NODES
AQUIFER
AQUITARD
NO FLOW BOUNDARY

b. Model calibration

The model was calibrated by attempting to recreate, under steady state conditions, a reasonable facsimile of known head distributions and gradients. Since the recharge rate and boundary conditions are only approximately known, several different recharge rates and boundary conditions were modeled. Recharge rates were varied from approximately 10 to 50 percent of available precipitation. The transmissivity of constant head nodes was varied over several orders of magnitude until the simulated steady state head distribution, for a given recharge rate, approximated actual head distributions and gradients. The effects of pumping wells were approximated by assigning observed head values to the appropriate constant head nodes. This reduces boundary effects associated with pumping a small cross-sectional volume.

c. Application of model to study area

This model simulates a two-dimensional cross-sectional flow field as an approximation of natural conditions. Application of the model tests the viability of a range of recharge and boundary conditions. It also indicates areas where a more comprehensive three-dimensional model of the flow field is required in order to provide insights into the the cause of the observed flow patterns.

The shortcomings of this model are:

1. The three-dimensional flow field can not be directly simulated or quantified.
2. Downdip flow can not be directly simulated or quantified.
3. The effects of the Delaware River are ignored.

The benefits are:

1. A larger number of layers can be simulated with less computer time. This permits a more refined simulation of flow in the x-z plane than could be obtained with fewer layers.
2. Downdip flow can be indirectly evaluated by allowing water to flow out of the bottom of the model. The ratio of recharge to flow out of the bottom layer CHNs was evaluated for each simulation. This ratio should approximate the actual ratio of recharge to water lost to regional flow and/or pumping wells.
3. The boundary conditions associated with the Delaware River are not well known. The cross section is located far from this unknown boundary.

In summary, the model serves as a useful tool to enhance understanding of the flow systems operating in this area.

5.3.1 Steady state simulation

The response of the model to average annual hydrologic conditions was tested by solving the finite difference analog of the the steady state ground-water flow equation. Input data is contained in Appendix 6.

CHNs were required in the bottom layer(s) of the model, otherwise, water levels in the model built up to unrealistic elevations (see Appendix 6). Increasing the K of top layer CHNs (representing streams and swamps) could not accommodate all of the flow. This indicates that water is being lost either to the regional flow system or to the Delaware River.

Runs in which the model included a bottom layer of CHNs obtained better matches between simulations and field conditions (see Appendix 6). This layer simulates loss of water to the lower artesian zone and/or downdip parts of the aquifer. Additionally, for recharge rates equal to one-half or more of the average annual runoff, flow to the deep artesian zone is required to keep head values within 3 m of observed head values. In these cases, approximately one-third to one-half of recharge discharges to the lower artesian zone.

For a recharge rate of approximately one-fourth of maximum available precipitation, flow to the lower artesian zone is not required to keep head values in a reasonable range. Enough water is lost through the nodes representing surface water bodies and the end nodes of layer two (representing the shallow artesian zone). However, vertical gradients were not as close to observed vertical gradients as those produced by simulations with a bottom layer of CHNs.

In all cases, the locations of local flow system boundaries are variable. Local flow system boundaries extend to layer 2 beneath the nodes representing Raccoon Creek. Local flow system boundaries extend to layer two beneath the nodes representing Maple Swamp, Moss Branch, and Little Timber Creek only when flow to the regional flow system is reduced or when water table topography is increased. In cases where local flow system boundaries beneath

Maple Swamp, Moss Branch, and Little Timber Creek do not extend to layer two, intermediate flow systems are present. The local flow system extends into layer two in areas where aquitards are absent.

Aquifer heterogeneities appear to create stagnation points in layers two, three, and four. For example, stagnation points are located beneath thick aquitards (nodes 14-17). These represent the boundaries of intermediate flow systems. Stagnation points in shallower layers are also dependent on aquifer and aquitard geometry. Where aquifer geometry is complex, the stagnation points are vertically offset. The result is an extremely complex flow system; with local, intermediate, and regional components.

Where aquifer geometry is simple (nodes 19-33), the resultant head distribution is simple. Potentiometric contours extend from the top layer to layer two with a nearly vertical orientation. The entire section, down to the aquitard separating the middle and lower aquifers, appears to be under water table conditions.

Inspection of the contour plots indicates that only horizontally extensive (>250 m) aquitards are capable of maintaining significant vertical gradients ($>1 \times 10^{-2}$). This suggests that, where average vertical gradients between different levels of the aquifer are smaller than 1×10^{-2}, the aquitards separating those levels are not areally extensive.

The results of the steady state simulations corroborate several conclusions reached by other methods:

1. A complex flow system, with regional, intermediate, and local components, exists in the study area.

2. The locations and shapes of boundaries between flow systems are complex due to aquifer geometry, climatic conditions, and ground water-surface water-relationships.

3. A significant portion (10 to 33 percent) of available recharge is lost to the regional flow system by both horizontal and vertical flow paths.

4. Additionally, flow lines in local flow systems can extend down to the base of the middle aquifer. Flow lines in the regional flow system are more horizontal than predicted by the model, because of the error introduced by approximating the three-dimensional flow field with a two-dimensional model.

5.3.2 Transient Simulations

The response of the model to short-term variations in climatic and boundary conditions was tested by first assigning storage coefficients (S) and specific yield (Sy) values to nodes in the model, and then solving the finite difference analog of the transient ground-water flow equation. Input data is summarized in Appendix 6.

S and Sy values were assigned equal values within each layer of the model. Although this approach does not account for variations of S and Sy within a given layer, a more detailed model can not be justified by the data. The amount of error introduced by this approximation is unknown, and may be significant.

The two-dimensional approximation to the three-dimensional flow field is undoubtedly less accurate in this case, as compared to the steady state case. However, the results can help to qualitatively evaluate the effects of transient events on ground-water flow.

Results are contained in Figure A6.5 (Appendix 6). The flow field is more complex than the steady state flow field. Flow directions change within one day of the start of the simulation. The change in flow directions is especially obvious near columns 19 and 20. The spatial variability of aquifer characterisitics in this part of the model is also more complex than in other parts of the model.

The results indicate that flow paths are dependent on climatic variations and local aquifer geometry. This causes flow directions to be temporally variable. This phenomenom is undoubtedly a factor in the study area. The amount of time required for the aquifer to return to steady state conditions can not be determined by the model because of the many assumptions and approximations. However, it is obvious that if climatic changes are frequent, flow directions will also change frequently.

6.0 CONCLUSIONS

1. Logan Township is located within the outcrop area of the Potomac-Raritan-Magothy aquifer system, which in this area consists of unconsolidated Cretaceous and Quaternary age sediments. Inter- and intraformational erosion have created complex hydrogeologic conditions.

2. A complex ground water flow system; with local, intermediate, and regional components, exists in the study area. The complexity is the result of: a heterogeneous, anisotropic aquifer; surface water-ground water interactions; climatic variations; and pumping wells.

The complexity of the flow system is evidenced by variable flow directions both within and between different levels (i.e., water table, shallow artesian) of the aquifer.

3. Logan Township is located in a regional recharge area. Estimates based on regional water level and numerical models studies suggest that up to 45 percent of available precipitation is lost to the regional flow system.

4. All information indicates that contaminants introduced at the surface can, where subsurface conditions permit, migrate downdip and/or vertically downward to deeper portions of the aquifer, and become incorporated with the regional flow system. The vertical

flow component is partly dependent on climatic conditions. Additionally, the vertical flow component is enhanced by pumping wells and on land disposal of waste fluids. Due to the heavy use of this aquifer, the fate of the contaminants will be of long term concern.

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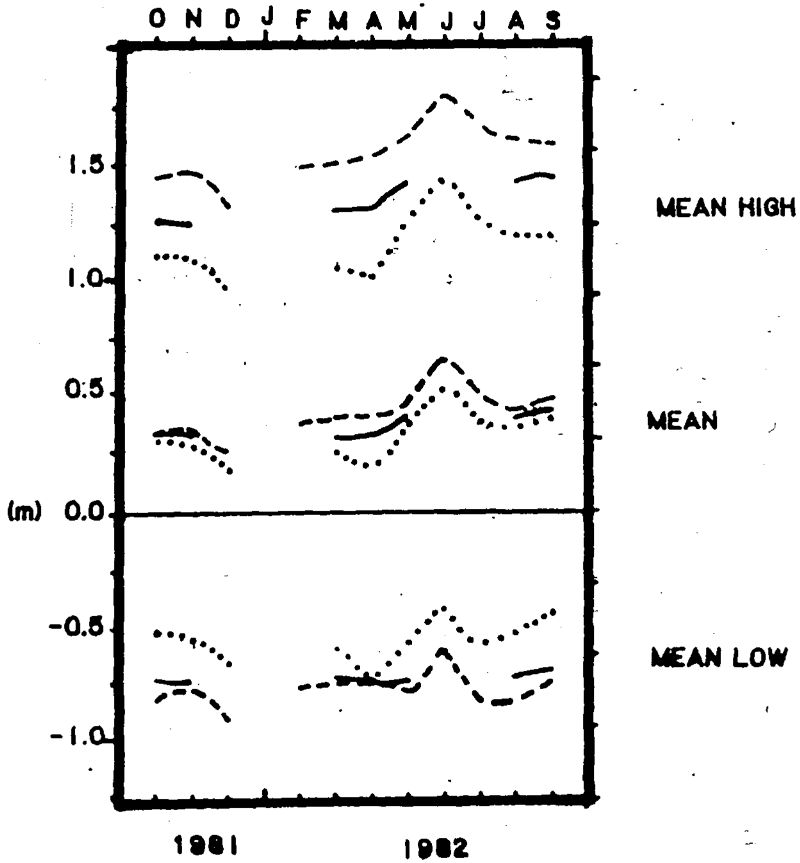
Appendix 1

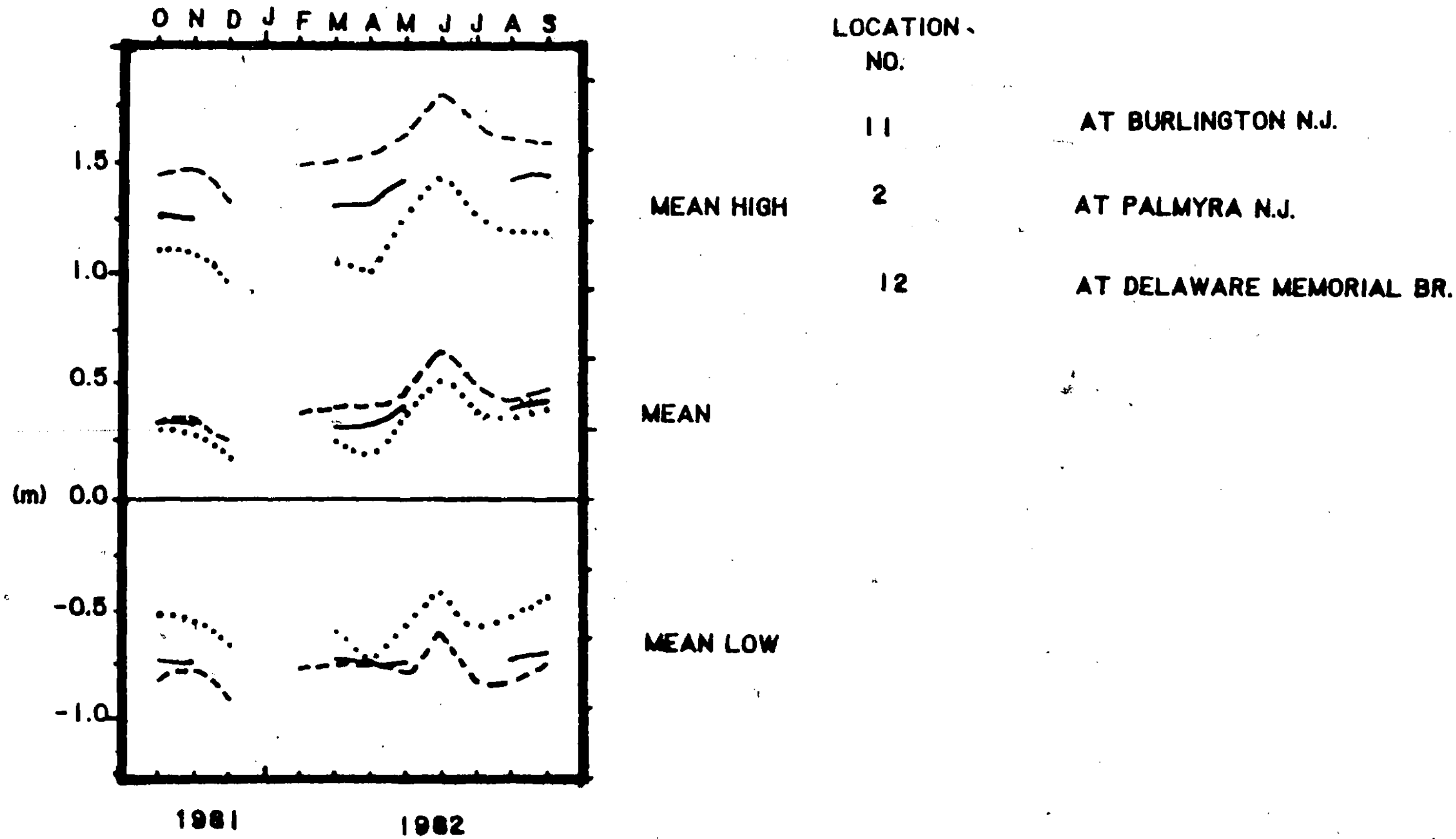
Surface water data

FIGURE A.1. MONTHLY MEAN RIVER STAGE   FROM BAUERSFELD ET AL. (1983)



LOCATION NO.	
11	AT BURLINGTON N.J.
2	AT PALMYRA N.J.
12	AT DELAWARE MEMORIAL BR.

FIGURE A.1. MONTHLY MEAN RIVER STAGE FROM BAUERSFELD ET AL. (1983)



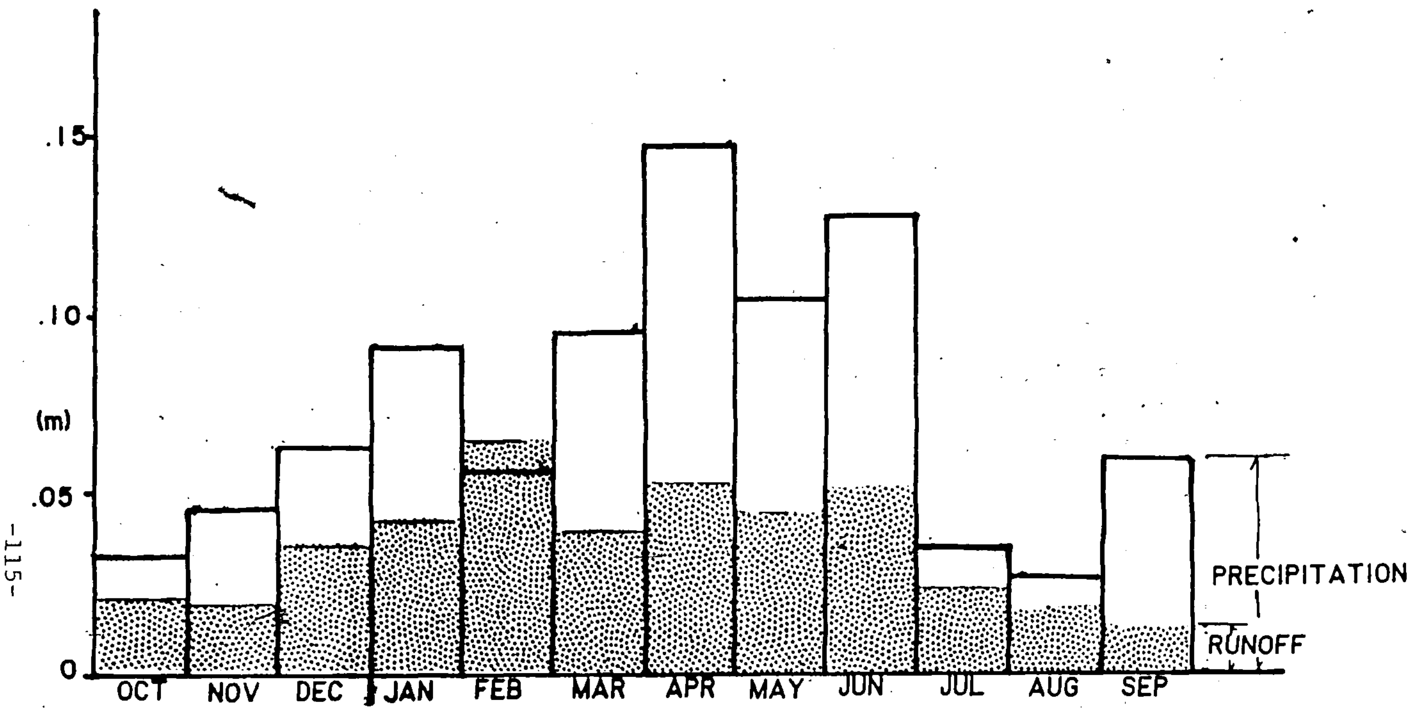


FIGURE A2. MEAN MONTHLY RUNOFF AND PRECIPITATION.
PRECIPITATION-MARCUS HOOK no.7 (FIG. 1) FROM NOAA
RUNOFF-SWEEDESBORO no.8 FROM BAUERSFELD ET AL. (1983)

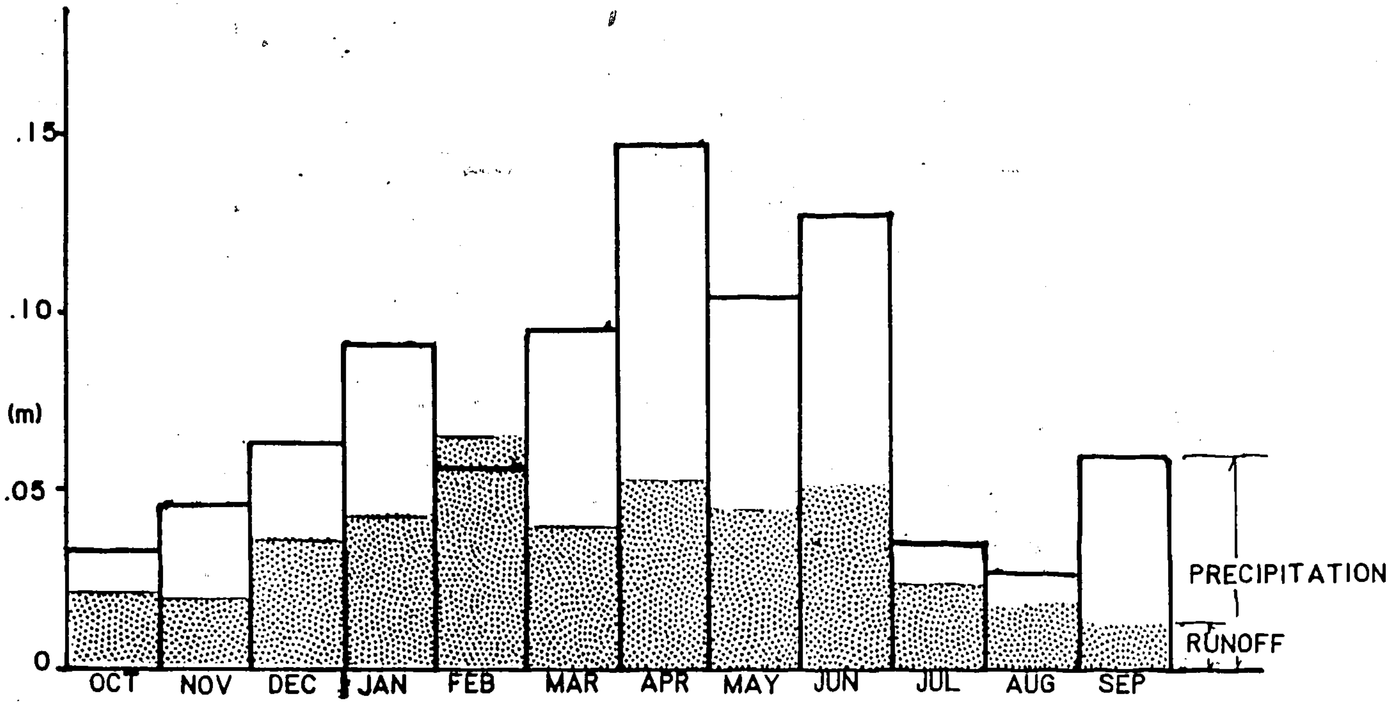


FIGURE A2. MEAN MONTHLY RUNOFF AND PRECIPITATION.
PRECIPITATION-MARCUS HOOK no.7 (FIG. 1) FROM NOAA
RUNOFF-SWEEDESBORO no.8 FROM BAUERSFELD ET AL. (1983)

APPENDIX 2

Heavy Mineral Analysis Procedures

Carver (1973) suggests that similar size non-opaque heavy mineral grains have similar hydraulic characteristics. Most samples chosen for heavy mineral analysis were judged visually to have similar grain size distributions, in the range of fine to coarse sand with less than 10 percent gravel and silt/clay. Several samples with grain size distributions falling outside this range were analyzed also.

Surface grab samples from different locations were used to check on the areal distribution of heavy minerals. Near surface, hand auger samples were also evaluated.

Split spoon sampled borings were used to check on the vertical distribution of heavy minerals. One or more samples from a given boring were analyzed.

The 2 to 4 phi size fraction of the selected samples were separated in tetrabromoethane (s.g. 2.83), acid treated, and permanently mounted on glass slides. A minimum of 400 non-opaque grains per sample were identified. The ribbon method of point counting was used (Carver 1973).

The results were graphically compared with the results (averages) of other heavy mineral studies (ie. Groot 1955, Glaser 1969, and McCallum 1957). Where possible, vertical sequences were tentatively correlated with the appropriate stratigraphic units.

SAMPLE GROUPINGS

A	B	C
102-35, 103-10, 103-40	102-50, 104-45, CL3-35	102-20, SDW-95
104-15, 104-35, 106-20	COOPER1, 106-50*	104-65, 107-45
2*		CL1-12, CSP-3
		30, 104-16a*
		CL3-14*, CL4-42*
	Groot-Patuxent, Magothy	Groot-Patapsco
	Glaser-Magothy	Glaser-Patapsco,
		Patuxent

*-Samples contained significant clay/silt.

Glaser- (1969)

Groot- (1955)

Table A2.1
Results of Heavy Mineral Study

Sample no.	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
SDW 95h(+4)	122	87	13	24	8	0	135	0	0	0	0	5	5	0	0	3518
102 50h(+3)	108	24	7	110	18	9	95	8	5	1	0	3	9	2	2	614
102 35h(+2)	47	42	10	58	18	20	115	0	6	14	0	46	3	6	5	1176
102 20h(+1)	277	21	7	16	1	3	86	4	0	0	0	0	0	1	0	539
103 40h(*2)	85	17	10	57	14	10	137	7	10	0	2	9	24	3	7	1266
103 10h(*1)	128	26	14	46	14	18	97	9	23	23	0	18	1	0	7	894
104 16a(-̂5)	65	66	17	13	1	0	229	0	0	0	0	5	3	7	2	2073
104 65h(-̂4)	124	22	12	80	10	2	142	2	0	0	0	4	2	2	2	3354
104 45h(-̂3)	88	62	6	99	34	22	86	0	2	5	0	7	2	6	2	1423
104 35h(-̂2)	72	19	7	24	3	5	225	2	5	1	23	0	15	0	0	909
104 15h(-̂1)	40	12	3	47	19	19	92	14	58	31	0	36	11	0	19	467
106 50h(¥2)	79	40	9	96	15	0	115	9	8	0	1	2	9	0	6	1168
106 20h(¥1)	35	35	5	37	6	24	56	3	8	3	12	127	38	0	11	536
107 45h(o2)	108	50	12	47	14	0	172	0	1	0	0	0	1	5	1	1977
107 20h(o1)	74	22	11	52	19	18	99	34	1	21	9	50	11	2	10	642
CL1 12h(▯)	139	41	4	6	3	2	103	0	0	0	0	0	0	2	0	1284
CL3 35h(v̂2)	55	85	7	185	16	0	28	0	0	0	3	0	19	3	0	1287
CL3 14h(v̂1)	71	82	5	25	2	1	210	0	0	0	0	0	3	6	0	1321
CL4 42h(∀̂2)	128	6	11	130	4	2	67	3	0	0	0	0	0	1	1	1831
CL4 10h(∀̂1)	65	17	7	45	16	12	106	6	10	16	13	45	30	4	5	570

Table A2.1
Results of Heavy Mineral Study

Sample no.	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
SDW 95h(+4)	122	87	13	24	8	0	135	0	0	0	0	5	5	0	0	3518
102 50h(+3)	108	24	7	110	18	9	95	8	5	1	0	3	9	2	2	614
102 35h(+2)	47	42	10	58	18	20	115	0	6	14	0	46	3	6	5	1176
102 20h(+1)	277	21	7	16	1	3	86	4	0	0	0	0	0	[illegible]	0	539
103 40h(*2)	85	17	10	57	14	10	137	7	10	0	2	9	24	3	7	1266
103 10h(*1)	128	26	14	46	14	18	97	9	23	23	0	18	1	0	7	894
104 16a(^5)	65	66	17	13	1	0	229	0	0	0	0	5	3	7	2	2073
104 65h(^4)	124	22	12	80	10	2	142	2	0	0	0	4	2	2	2	3354
104 45h(^3)	88	62	6	99	34	22	86	0	2	5	0	7	2	6	2	1423
104 35h(^2)	72	19	7	24	3	5	225	2	5	1	23	0	15	0	0	909
104 15h(^1)	40	12	3	47	19	19	92	14	58	31	0	36	11	0	19	467
106 50h(∀2)	79	40	9	96	15	0	115	9	8	0	1	2	9	0	6	1168
106 20h(∀1)	35	35	5	37	6	24	56	3	8	3	12	127	38	0	11	536
107 45h(o2)	108	50	12	47	14	0	172	0	1	0	0	0	1	5	1	1977
107 20h(o1)	74	22	11	52	19	18	99	34	1	21	9	50	11	2	10	642
CL1 12h(▯)	139	41	4	6	3	2	103	0	0	0	0	0	0	2	0	1284
CL3 35h(v̂2)	55	85	7	185	16	0	28	0	0	0	3	0	19	3	0	1287
CL3 14h(v̂1)	71	82	5	25	2	1	210	0	0	0	0	0	3	6	0	1321
CL4 42h(∀̂2)	128	6	11	130	4	2	67	3	0	0	0	0	0	1	1	1831
CL4 10h(∀̂1)	65	17	7	45	16	12	106	6	10	16	13	45	30	4	5	570

Sample No.	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
G 2h(x1)	66	17	3	27	3	11	77	4	26	26	14	81	53	3	10	425
G 9h(x2)	69	15	10	54	5	36	77	19	5	55	15	53	23	5	9	625
G 30h(x3)	241	9	12	59	7	9	43	14	3	8	0	7	2	2	1	1479
COOP 1h(x5)	34	46	8	170	3	9	130	0	0	0	0	0	0	0	0	1338
CSP 3h(x4)	124	1	14	7	1	1	16	4	0	0	0	0	1	3	0	727
Groot (1955)																
Patuxent(T1)	48	53	18	200	21	0	44	0	0	0	0	0	0	0	0	558
Patapsco(T2)	130	44	57	12	2	1	132	3	2	1	1	0	0	0	0	1885
Magothy(T3)	37	48	13	239	10	1	48	0	0	0	0	0	3	0	0	494
N.J. (T4)	68	44	16	42	8	4	196	0	0	0	0	0	4	8	0	186
Glaser (1969)																
Patuxent(R1)	178	58	4	107	24	0	20	0	0	0	0	0	2	0	0	1708
Patapsco(R2)	207	98	10	29	0	0	38	0	0	0	0	0	0	0	0	2122
Magothy(R3)	68	48	3	229	36	0	3	0	0	0	0	0	0	0	0	679

A- Zircon, B- Tourmaline, C- Rutile, D-Staurolite, E- Kyanite, F- Epidote, G- Alterites, H- Sphene, I- Garnet, J- Pyroxenes, K- Andalusite, L- Amphiboles, M- Sillimanite, N- Brookite, O- Chloritoid, P- Opaques

Sample No.	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
G 2h(x1)	66	17	3	27	3	11	77	4	26	26	14	81	53	3	10	425
G 9h(x2)	69	15	10	54	5	36	77	19	5	55	15	53	23	5	9	625
G 30h(x3)	241	9	12	59	7	9	43	14	3	8	0	7	2	2	1	1479
COOP 1h(x5)	34	46	8	170	3	9	130	0	0	0	0	0	0	0	0	1338
CSP 3h(x4)	124	1	14	7	1	1	16	4	0	0	0	0	1	3	0	727
Groot (1955)																
Patuxent(T1)	48	53	18	200	21	0	44	0	0	0	0	0	0	0	0	558
Patapsco(T2)	130	44	57	12	2	1	132	3	2	1	1	0	0	0	0	1885
Magothy(T3)	37	48	13	239	10	1	48	0	0	0	0	0	3	0	0	494
N.J. (T4)	68	44	16	42	8	4	196	0	0	0	0	0	4	8	0	186
Glaser (1969)																
Patuxent(R1)	178	58	4	107	24	0	20	0	0	0	0	0	2	0	0	1708
Patapsco(R2)	207	98	10	29	0	0	38	0	0	0	0	0	0	0	0	2122
Magothy(R3)	68	48	3	229	36	0	3	0	0	0	0	0	0	0	0	679

A- Zircon, B- Tourmaline, C- Rutile, D-Staurolite, E- Kyanite, F- Epidote, G- Alterites, H- Sphene, I- Garnet, J- Pyroxenes, K- Andalusite, L- Amphiboles, M- Sillimanite, N- Brookite, O- Chloritoid, P- Opaques

Appendix 3

Detailed Outcrop and Split Spoon Descriptions

LOGAN LIQUORS OUTCROPS (LL)

<u>East End (Km)</u>

.25-2m yellow-orange silty fine SAND (weathering horizon?) little quartz and quartzite gravel and cobbles concentrated on surface.

1.5m Mottled or irregularly colored light to dark grey, red brown, green, dense, hard, carbonaceous silty clay. Few, thin (1 cm), discontinuous, sub-angular, iron-oxide stained, m-f sand stringers interbedded with silty clay. Iron oxide and sulfide cemented concretions and Mica common. Rare boulders and cobbles of quartzite. Top of clay slopes to west toward Raccoon Creek. Clay is jointed, joint surfaces are mineralized (oxides and sulfides), which imparts fissility to outcrop.

<u>West End (Km)</u>

2.5 m Trough, cross-stratified fine gravel and subround to subangular c-m sand in beds approximately 0.3 m thick. Gravel composed of round to sub-round quartz and quartzite. Coarser grained layers are stained by iron oxides. Trace of lignite. Rare, irregularly shaped dark grey clay clasts or blobs.

CURTIS SAND PIT (CSP)

West Wall - 5 m exposure (Kp)

1m-fill? Subangular to subround, white to light brown, m-c SAND and c-m Gravel (quartz, quartzite, and chert) Little coal and weathered bricks or Triassic sandstone fragments.

2m Trough cross-stratified to massive, well sorted, white to light brown, sub-angular, m-c SAND in beds .1 - .5m thick. Irregularly shaped and oriented iron oxide stains prominent. SAMPLE CSP-3.

0.75m Interbedded, sub-round, light brown f. GRAVEL and c. SAND. Two distinct horizontal bands (2-5cm) of heavy minerals; oppositely dipping iron oxide stained bands.

1.25m 0.1 to 0.25m thick trough shaped beds of sub-round to sub-angular GRAVEL (quartz, quartzite, and chert) some c sand and heavy mineral bands.

South End (Kr)

Grey, green, black, and red, carbonaceous and micaceous CLAY, some silt. Some places on the pit floor are laminated (mm scale) CLAY some silt and f SAND some silt. Iron oxide and sulfide concretions common. Surface of clay appears to dip to the Southwest. SAMPLE CSP-4

East Wall - 3m exposure (Kp)

0.25-1m orange, f-m SAND, some silt (soil layer)

2-2.5m Trough cross-stratified, moderately sorted, yellow to orange, sub-angular, m-c SAND in beds 0.05-0.1m thick. Some beds have f. GRAVEL and heavy mineral lag. Dark brown, discontinuous, SAND and CLAY laminae (2-5cm thick) form the dip slopes of some cross-beds; iron oxide stains mark others. The SAND and CLAY laminae more common and thicker at top of section.

.3m Iron oxide and clay cemented, poorly sorted m-c GRAVEL (quartz), interbedded with m-c Sand and silty clay. Beds range from 2 - 10cm thick. Trace gravel size clay clasts.

PAZ BROTHERS SAND AND GRAVEL

South Wall 2.5m exposure (Kp)

1m fill

1.5m Trough cross stratified, orange to light brown, sub-angular to sub-round, m-c SAND in beds 0.25 to 0.5m thick. Some beds contain little silt. Iron oxide stains are common. Irregularly shaped (.05-.1m dia.) purple mottles filled with white f SAND (Root molds?). In some places this sequence is topped by 0.25 - 0.5m of hard gray to white CLAY. CLAY present as plugs or lenses. At one location, the SAND is underlain by 0.1m gray, carbonaceous, CLAY, little Silt, trace Gravel which appears to be the "floor" of a channel.

HAND AUGER BORING 1 (HA1)- Where Moss Branch crosses Route 44 (Q)

0-0.3m Light brown (10 yr 4/2) to black f-m SAND, some Silt, trace Gravel (fill)

0.3-6m olive grey (5Y 5/1) m-f SAND, little Silt with rare thin beds (0.1m) of olive brown (5Y 4/4) CLAY, some silt. Sample 2-h

HAND AUGER BORING 2 (HA2) - Cedar Swamp Road

0-0.2m Light to Dark yellow orange (10 yr 2/6 to 10 yr 6/6) f-m SAND, trace silt, with dark browncarbonaceous SILT (soil horizon)

0.2-1.8m Light to Dark yellow orange (10 yr 2/6 to 10 yr 6/6) f-c SAND, trace Silt. 0.1m thick CLAY, little SAND at 1.5m.

HAND AUGER BORING 3 (HA3) near Moss Branch and Cedar Swamp Rd.

0-2m Dark brown PEAT

2-7m Red brown PEAT

7-7.5m Light Olive grey (5Y 5/2) carbonaceous, sticky SILT and CLAY

HAND AUGER BORING 4 (HA4) - near 108

0-0.3m Muck

0.3-0.9m Light olive grey (5Y 5/2) CLAY with orange (10 yr 5/4) mottles of f SAND, some Silt and Clay

0.9-1.5m Hard, light olive grey (5Y 5/2) m SAND, little Silt, with orange (10 yr 5/4) mottles of m SAND

1.5-3.0m Orange (10 yr 5/4) to light olive grey (5Y 5/2) c-m SAND, some f Gravel. Sample 9-h

HAND AUGER BORING 5 (HA5) - 15m South Oak Grove Rd and Moss Br

0-1m Light brown to light orange mottled f-m SAND, little f Gravel. 0.2m thick carbonaceous CLAY at 0.3m

1-1.5m Orange (10 yr 5/4) m-f SAND, some Clay

1.5m COBBLE

HAND AUGER BORING 6 (HA6) - Oak Grove RD and Moss Br

0-0.1m water

0.1-2m light olive gray (5Y 5/2) carbonaceous f SAND and SILT

EPA BORING 108

22.86-	alternating layers of SAND and CLAY; white and yellow.
23.47-	.91m WASH
23.99m	.08m CLAY some SILT; white/light clay
	.02m v.f. SAND; orange-brown
	.02m v.f. SAND and CLAY; light yellow
	.02m CLAY; white
	.08m f. SAND; light yellow
	.122m v.f. SAND trace silt; white
25m	.10m CLAY, little Sand; finely laminated orange and grey.
	.15m CLAY, grey
	.05m f. SAND, grey
	.12m Clayey SAND grading to Sandy CLAY
	.15m CLAY, some silt, little sand.
	.10m CLAY, f. Sand stringers; finely laminated orange and grey
	.05m CLAY, thin Sand laminae; olive brown

S-11 35m

3cm	gray and yellow laminated CLAY
3cm	orange (10 yr 5/4) CLAY and SAND
9cm	white and red variegated and mottled CLAY, trace SAND stringers. Small iron oxide concretions.

S-2 3.4 m depth (.15m diameter core sample)

.2m ORANGE (10 yr 5/4) to gray haphazard mix of CLAY, some Silt, little Sand, and f-m GRAVEL, little clay (slump feature)

Appendix 4

Table A4.1
Lithofacies Data

Boring	Surface Elev.	Total Depth	INTERVAL Sand +3.0-	Clay -6.1	Sand -6.1-	Clay -15	Sand +3 - -27	Q thick-ness
RES (a,b)								
A	2.8	7.6	7.0	0.6				2.7
B	3.8	17.9	7.6	1.5	1.2	7.0		4.5
C	4.1	12.2	9.1	0				3.0
D	3.6	12.2	8.5	0.6				4.5
E	2.8	6.1	3.0	3.0				1.5
F	5.2	9.1	6.4	0.6				1.0
G	6.7	9.1	3.0	2.4				3.0
H	2.7	7.6	6.7	1.5				3.0
L	2.4	6.1						6.1
M	2.6	6.1						6.1
N	2.0	7.6						7.6
O	2.7	4.6						4.6
P	3.0	9.1	6.7	1.5				3.0
Q	7.0	9.1						9.1
R	2.9	6.1						6.1
S	2.9	9.1	6.1	3.0				2.3
U	6.6	7.6						6.1
V	4.6	8.5						3.7
W	4.1	6.1						4.5
EE	7.2	18.6	7.6	1.5	7.0	2.1		3.0
II	2.4	12.8	8.5	0				3.0
DP1	2.2	27.4	0	8.2	7.6	1.5	9.8	15.2
DP2	3.2	27.4	7.6	1.5	4.5	4.5	19.8	3.0
DP3	6.8	27.4	7.6	1.5	6.7	2.4	20.4	6.1
DP4	3.5	39.6	7.9	1.2	9.1	0	26.2	4.8
T1	1.5	32.6	6.7	0.9	8.5	0.6	24.1	2.1
T2	2.3	30.8	5.1	3.0	7.3	1.8	17.7	4.1
T3	2.7	38.7	6.1	3.0	9.1	0	26.8	2.1
T4	4.0	43.3	7.0	2.3	9.1	0	22.2	2.1
MA1	0.3	21.6	4.5	1.5	8.2	0.9		1.5
MA2	0.6	21.3	5.1	1.5	6.7	2.4		1.5
MA3	0.9	21.9	5.7	1.2	8.2	0.9		1.5
MA4	1.2	21.9	7.0	0.3	7.6	1.5		1.0
MA5	0.6	21.6	3.9	2.7	7.3	1.8		1.0
MA6	0.6	20.1	2.7	3.9	4.2	4.8		3.0
MA7	0.3	20.1	1.2	5.1	8.2	0.9		4.6
MA8	0.6	15.5	3.6	3.0	8.5	0.3		3.0
MA9	0.6	21.9	5.5	1.2	5.5	3.6		1.5
MA10	0.3	18.9	0	6.4	7.3	1.8		6.4
MA11	0.3	16.8	0.6	5.7	5.7	3.4		5.5

Boring	Surface Elev.	Total Depth	Sand +3.0-	Clay -6.1	INTERVAL Sand -6.1-	Clay -15	Sand +3 - -27	Q thickness
SHELL (c)								
B1	3.4	31.1	9.1	0	3.9	5.1	25.0	1.8
B2	4.3	15.8	9.1	0				1.8
B3	4.0	18.9	8.8	0.3	3.7	5.1		4.0
B4	6.1	15.5	8.8	0.3				1.5
B5	7.3	15.4	9.1	0				0.5
B6	6.4	32.8	8.8	0.3	8.2	0.9	24.4	2.1
B7	6.1	15.8	9.1	0				1.5
B8	6.1	31.1	9.1	0	4.2	4.8	16.2	4.0
B9	3.7	15.8	8.2	0.9	6.1	2.7		1.5
B10	7.0	32.8	6.4	2.7	8.8	0.3	23.8	0.5
B11	8.5	15.8	6.1	3.0				0.2
B12	7.0	31.1	8.5	0.6	5.7	3.3	18.3	1.2
B13	5.5	31.1	6.7	2.4	7.3	1.8	23.2	1.8
B14	6.7	31.1	5.1	3.9	5.5	3.6	14.0	4.0
B15	3.0	15.8	7.0	2.1	6.1	0.6		2.7
B16	6.4	29.5	6.7	2.4	5.1	4.0	20.4	3.0
B17	4.0	15.8	4.5	4.5	3.9	1.8		2.4
B19	3.4	15.8	5.7	3.4	3.4	3.9		?

Boring	Surface Elev.	Total Depth	INTERVAL Sand +3.0-	Clay -6.1	Sand -6.1-	Clay -15	Sand +3 - -27	Q thickness
B20	2.4	15.8	7.0	1.5	4.5	2.7		?
B21	3.7	31.1	7.3	1.8	8.2	9.1	26.2	3.5
B22	1.8	15.8	7.3	0.6	6.7	1.2		2.1
B23	4.6	30.8	7.0	2.1	8.8	0.3	26.8	2.1
B24	3.4	31.1	7.0	2.1	8.2	0.9	20.7	?
B25	2.1	15.8	9.1	0	7.6	0		1.8
B26	5.5	15.8	2.4	6.7				1.8
B27	4.0	31.1	8.8	0.3	8.8	0.3	30.2	1.5
B28	3.4	15.8	8.8	0.3	6.1	0.3		1.2
B29	2.1	15.8	8.5	0.6	7.3	0.3		1.2
B30	2.4	31.1	8.5	0	3.4	5.7		0.9
B31	1.8	15.8	6.1	1.8	5.4	2.4		1.8
B32	0.9	31.1	7.0	0	7.6	1.5	25.0	10.2
B33	0.0	12.8	1.5	4.5	3.9	2.4		12.8
B34	0.6	31.1	5.7	0.9	8.2	0.9	25.6	9.4
B35	0.9	13.7	3.9	3.0	5.4	1.2		8.2
B35A	0.6	15.2	2.4	3.9	5.1	3.6		10.1
B36	6.7	15.2	7.9	1.2				1.0
B37	7.9	25.0	6.7	2.4	3.9	5.1	16.8	14.6
B38	7.9	25.0	5.7	3.4	7.6	1.5		15.5
B39	8.8	25.0	9.1	0	5.4	3.6		18.8
B40	8.5	24.4	9.1	0	6.7	2.4		18.5
B41	2.7	24.4	4.8	3.9	1.8	7.3		17.1
B42	2.7	24.1	0.9	8.1	0	9.1		18.2
B43	2.7	30.5	0.9	8.1	3.0	6.1		26.5
B44	4.3	8.2	3.0	4.2				
B45	3.0	8.2	2.7	4.5				
B46	3.0	8.2	0.9	7.9				
B47	3.0	14.9	0	9.1	4.2	1.5		
B48	3.7	9.1	1.8	7.0				
B49	4.3	8.2	4.8	2.1				
B50	2.1	11.3	1.8	7.3				
10A	4.0	56.1	7.0	2.1	4.5	4.5	20.7	6.4
10B	5.2	62.2	8.5	0.6	9.1	0	27.4	2.4
8A	2.1	56.1	8.2	0	7.9	1.2	23.8	6.1
6A	2.1	52.7	6.1	2.1	3.9	5.1	20.7	4.6
6B	1.5	53.0	2.7	4.8	7.6	1.5	21.6	4.0
6C	5.8	50.0	4.5	4.5	8.2	0.9	21.9	3.0

Boring	Surface Elev.	Total Depth	INTERVAL Sand +3.0-	Clay -6.1	Sand -6.1-	Clay -15	Sand +3 - -27	Q thick-ness
MONSANTO (d,e)								
PWW	3.7	27.2	5.4	3.6	4.5	4.5		6.1
PWE	3.7	26.9	5.4	3.6	4.5	4.5		6.4
TW1	1.5	45.1	1.2	6.4	0	9.1	5.7	24.9
TW2	3.0	53.3	7.6	1.5	2.4	6.7	20.3	15.8
TW3	0.9	61.0	5.4	1.5	2.4	6.7	12.3	13.7
TW4	2.4	64.9	5.4	3.0	0.6	8.5	16.6	12.2
TW5	1.5	68.6	2.4	5.1	1.5	7.6	10.9	15.8
TW7	1.5	64.0	1.5	6.1	2.4	6.7	12.7	14.3
1	4.0	24.1	3.4	5.7	7.0	1.5		21.3
4	2.4	35.6	4.3	4.3	0	9.1		24.3
5	3.0	33.5	3.0	6.1	0	9.1		24.3
6	4.9	23.8	1.5	7.6	1.8	7.3		25.8
9	4.9	24.4	0	9.1	3.0	6.1		21.3
10	4.0	19.8	0	9.1	3.0	6.1		24.3
12	4.6	20.1	1.5	7.6	2.1	7.0		
13	5.5	20.1	4.3	4.8	0	9.1		25.8
14	4.6	20.1	0	9.1	2.4	6.7		24.3
15	4.3	24.4	0	9.1	0	9.1		23.7
17	8.5	19.5	7.6	1.5				
18	3.7	29.0	0	9.1	0	9.1		
19	3.4	33.5	0	9.1	0	9.1		
22	3.0	24.4	0.3	8.8	1.5	7.6		
23	2.1	20.1	0	9.1	7.6	1.5		21.3
25	4.9	24.4	4.2	4.8	0.6	8.5		
26	4.6	24.4	3.9	5.1	1.5	7.6		
27	2.7	22.9	4.8	3.4	3.0	6.1		15.4
28	2.4	24.4	6.1	2.4	0	9.1		6.1
29	2.7	24.4	6.1	2.7	1.5	7.6		6.1
32	2.7	23.8	7.0	1.8	2.4	6.7		7.0
33	2.7	19.2	7.9	0.9	4.0	5.1		
35	5.2	26.9	1.5	7.6	1.5	7.6		
36	5.2	22.6	5.1	4.0	0.9	8.2		
38	3.7	23.8	4.8	4.3	0.6	8.5		
39	3.7	24.4	4.5	4.5	1.5	7.6		7.3
PURELAND (f)								
L1	4.6	115.8	9.1	0	9.1	0	27.4	?
L2	4.6	58.2	8.8	0.3	5.5	3.6	21.9	?
L3	1.5	107.9	7.6	0	9.1	0	25.9	7.0
L4	1.5	62.2	7.6	0	5.8	3.3	19.5	?
L5	4.6	97.2	6.1	3.0	8.2	0.9	21.9	?
L7	1.5	63.1	4.5	3.0	6.1	3.0	19.8	10.7
L8	1.5	61.3	3.7	3.7	5.1	3.9	10.4	14.3
L9	1.5	62.8	6.1	1.5	8.2	0.9	23.5	?
OB1	3.0	68.9	7.6	1.5	6.1	3.0	18.3	?
MW1	3.0	25.0	7.6	1.5	1.5	7.6		2.4
MW2	1.5	25.0	3.0	4.6	7.0	2.1		2.4

Boring	Surface Elev.	Total Depth	INTERVAL Sand +3.0-	Clay -6.1	Sand -6.1-	Clay -15	Sand +3 - -27	Q thick-ness
MW3	1.5	25.0	4.0	3.6	1.5	7.6		13.7
DOT (g)								
64-871-2	1.5	10.0	5.5	2.1				
64-871-3	1.5	10.0	4.2	3.4				
360-3	3.4	14.0	9.1	0				
360-1	3.0	14.0	9.1	0				
270-51	2.7	12.2	5.8	3.0				
270-5	7.6	14.3	9.1	0				
270-8	7.9	14.6	9.1	0				
270-25	9.4	13.1	6.1	0				
270-40	9.1	12.5	5.1	0.9				
270-43	9.4	12.5	6.7	0				
BROS								
101	2.1	14.0	7.0	1.2				
103	3.0	16.7	9.1	0	6.7	0		6.5
104	3.0	31.1	8.8	0.3	9.1	0		10.7
105	2.7	15.5	8.8	0.3	6.4	0		
106	2.7	15.8	3.4	5.5	6.4	0.9		6.5
108	2.1	30.5	8.2	0	9.1	0		
SDW	4.3	30.5	8.2	0.9	7.6	1.5	26.3	10.7
S1	1.8	17.4	6.7	1.2	6.1	3.0		
S2	2.7	35.0	6.4	2.1	6.7	2.4	22.2	
S3	2.4	32.0	8.0	0.9	9.1	0	26.5	
S5	1.7	22.8	5.7	1.8	6.1	3.0		
S8	2.7	25.3	7.3	1.5	8.2	0.9		
S10	2.1	54.8	7.3	1.5	8.8	0.3	25.6	
S11	2.1	47.2	6.1	2.1	7.0	2.1	23.8	6.1
S12	2.4	70.1	7.6	0.9	9.1	0	25.9	
CLTL								
CL1	3.4	10.7	9.1	0				0.5
CL3	0.9	11.3	4.2	2.7	3.6	0.6		3.0
CL4	2.4	13.7	4.5	3.9	0.6	4.5		3.4
DW1	0.9	29.2	9.1	0	9.1	0	28.3	>3.0
DW2	2.4	29.9	7.6	1.5	9.1	0	27.1	3.0

Boring	Surface Elev.	Total Depth	INTERVAL Sand +3.0-	Clay -6.1	Sand -6.1-	Clay -15	Sand +3 - -27	Q thick-ness
AEI 15-399	3.0	36.9	4.5	4.5	4.5	4.5	28.3	3.0
PG 15-166	3.7	38.7	3.0	6.1	4.5	4.5	27.1	3.6
SQ 15-457	4.6	32.0	7.6	1.5	0.6	8.5	15.2	
HT 15-459	4.6	21.9	7.6	1.5	6.7	2.4		
PJC 15-468	3.0	29.0	1.5	7.6	7.9	1.2	18.0	
ST 15-456	4.0	22.6	4.5	4.5	8.2	0.9		
LP 15-398	0.6	18.3	0	6.7	6.1	3.0		>14.6
ED 15-386	2.7	18.6	5.1	3.6	7.9	1.2		
AG 15-453	4.6	18.6	6.1	3.0	7.6	0		
AF n30-236	4.6	21.3	4.5	4.5	3.4	5.7		
CL 15-170	2.1	53.6	8.2	0	9.1	0	23.4	1.0
GNC 15-137	4.6	71.9	1.5	7.6	6.4	2.7	17.1	1.8
BR 15-455	4.6	24.1	9.1	0	6.1	3.0		
DA 15-451	6.1	18.2	9.1	0				
PZ	3.0	38.4	7.0	2.1	5.8	3.3	23.5	
FE n30-2480	0.6	21.3	0	6.7	0	9.1		15.8
ME 15-462	2.1	20.8	8.2	0	4.2	4.8		
DU 15-467	3.0	30.2	7.3	1.8	4.2	4.8	20.7	
MUA n30-1448	1.5	35.0	4.5	2.7	4.2	4.8	18.2	2.9
SR30-63	4.6	13.7	9.1	0	4.5	0		4.6
SR30-62	3.0	13.1	6.4	2.7	3.6	0.3		3.0
SR30-57	4.6	10.7	9.1	0				
SR30-58	6.1	20.4	3.0	6.1	7.6	1.5		

Boring log sources: a. DWR(1981); b. RES files (DWR); c. Geraghty and Miller, Inc. (1972); d. Geraghty and Miller, Inc. (1965); e. Monsanto files (DWR); f. Geraghty and Miller, Inc. (1971); g. N.J. Department of Transportation (unpublished).

Appendix 5

Table A5.1
Gradient Data

Well Pair	Distance	6/24/81	7/16/81	7/19/81	7/23/81	10/22/81
RES(a)						
DP3-U	18.0					0.044
DP1-R	19.8					
CLTL-BROS						
CL2-D2	22.2	0.0059	0.0029	0.0053	0.0107	0.0079
CL3-D1	19.5	0.012	0.0022	0.0020	0.0033	0.0048
102-SDW	16.7					0.0021
		10/14/81	11/24/	12/4/81	1/25/82	1st/82
DP3-U		0.037		0.036	0.063	
DP1-R		0.047	0.034			0.019
		3/25/82	4/28/82	6/15/82	9/7/82	4th/82
DP3-U		0.046	0.047	0.071	0.058	0.03
DP1-R				0.034	0.031	0.054
		12/4/81	1/25/82	3/25/82	4/28/82	6/15/82
CL2-D2		0.0058	0.041	0.0027	0.0040	0.0011
CL3-D1		-0.0110	0.002	0.0025	0.0033	0.0095
102-SDW		0.0009		0.0025		0.0027
		9/28/83	11/7/83	12/23/83	1/10/84	
CL2-D2			-0.016			
S2b-S2c	17.7	0.0015	-0.0097	0.0007	0.0036	
S3b-S3c	16.4	0.0026		0.0052	-0.0035	
S4-102	6.1			0.0024	0.0020	
S8-107	13.7			-0.12	0.0006	
S9-108	14.0			0.0011	0.0004	
S11b-S11c	8.0	-0.013		0.015	0.018	

Positive downwards

	distance	8/23/72 b	9/21/72 b	10/3/72 b	10/16/72 b	11/30/73 c
Pureland + + Shell						
L3-L4	21.3	0.007	0.13	0.042	0.13	0.70
WT1-10A	43.0	0.024	0.03	0.025	0.02	
WT2-10B	43.0		0.05	0.04	0.021	
WT3-6B	33.5				0.015	
WT4-6C	33.8				0.11	

		11/16/78 c
L3-L4		0.13

a-Geraghty and Miller, Inc., from files of DWR, b-Geraghty and Miller, Inc. (1972), c-Walker (1983)

Table A5.2
Water Level Data
(values in m,MSL)

Site & Well	9/3/81	10/22/81	12/4/81	1/25/82	3/25/82	4/28/82	6/15/82
CLTL-BROS							
CL1				1.24	1.07	1.15	0.97
CL2	0.87	0.76	0.80	1.73	0.95	1.08	1.20
CL3	0.50	0.72	0.45	0.90	0.99	1.20	1.01
CL4	0.83	0.76	0.58	1.01	1.12	1.25	1.34
D1		0.62	0.71	0.86	0.94	1.13	1.20
D2		0.59	0.68	0.82	0.88	0.99	1.17
101	0.66		0.59				1.24
102	0.74	0.63	0.67		1.12		1.39
103	0.60	0.46	0.56		0.89		1.26
104a	0.63	0.52	0.32		0.94		1.22
104	0.70						1.38
105	0.62	0.55	0.63		0.91		1.26
106	0.53	0.48	0.35		0.84		1.10
107	0.54	0.47	0.67		0.87		
SDW		0.64	0.68		1.08		1.34
108					1.03		1.17

	6/30/82	7/30/82	11/29/82[d]	8/24/83[d]	9/28/83[e]	12/23/83[e]	1/10/84[e]
CL2	1.06	0.92	0.84	0.92			
CL3	1.10	1.17	0.82	0.84			
D1	1.09	0.92	0.74	0.80			
D2	1.00	0.86	0.60	0.66			
				11/7/83 (f)			
CL2				1.06			
D1				1.54			
D2				1.42			
S1a					0.73	1.02	0.94
S1b					0.71	0.81	1.03
S1c					0.53	1.13	1.05
S2b				1.60	0.41	0.94	1.00
S2c				1.77	0.38	0.92	0.94
S3a					0.54	1.17	0.94
S3b					0.45	1.01	0.78
S3c					0.41	0.92	0.84
S4					0.51	1.01	0.97
S5					0.41	0.96	0.87
S6					0.85	0.76	0.66
S8					0.37	1.79	0.76
S9					0.56	0.93	0.86

	6/30/82	7/30/82	11/29/82[d]	8/24/83[d]	9/28/83[e]	12/23/83[e]	1/10/84[e]
S11a					1.18		
S11b					0.12	0.91	0.78
S11c					0.22	0.79	0.63
101						0.99	0.95
102						1.02	0.96
103						0.97	0.84
104a						1.23	0.80
104						1.10	0.92
105						1.11	0.94
106						0.81	0.70
107						0.12	0.76
108						0.95	0.86

d-CLTL, from DWR files, e-NUS (1984), f-USGS unpublished data from 1983 synoptic water level study.

	10/14/81	10/22/81	11/24/81	12/4/81	1/25/82	3/25/82	4/28/82
RES (a)							
R	1.11		0.92				
U	1.25	1.33		1.50		1.78	1.86
DP1	0.17		0.25				
DP2							
DP3	0.59	0.58	0.57	0.58	0.72	0.91	1.04
DP4							

	1st/82	6/15/82	9/7/82	4th/82	11/7/83[f]
R	0.72	1.10	0.70	1.04	
U	1.33	2.30	1.69	1.09	
DP1	0.32	0.39	0.09	-0.03	1.05
DP2		0.87			1.29
DP3	0.68	1.13	0.66	0.51	
DP4		1.31			

Table A5.3
Well Construction Data

Site + Well	El. of screened interval (m,MSL)	Site & Well	El. of screened interval (m,MSL)
CL TL &BROS		CL TL &BROS	
CL 1	-7.6 - -8.2	S1a (e)	-0.21 - -2.0
CL 2	-6.1 - -6.7	S1b	-4.3 - -7.4
CL 3	-9.8 - -10.4	S1c	-9.1 - -12.2
CL 4	-4.5 - -6.0	S2a	-1.2 - -4.0
D1	-27.1 - -27.7	S2b	-9.1 - -12.2
D2	-26.5 - -27.1	S2c	-26.8 - -29.9
101 (f)	-7.6 - -8.2	S3a	-0.9 - -2.8
102	-6.1 - -6.7	S3b	-9.6 - -12.7
103	-9.8 - -10.4	S3c	-25.0 - -28.1
104	-2.4 - -3.0	S4	1.2 - -1.8
104a	-11.6 - -12.2	S5	-16.8 - -19.9
105	-8.5 - -9.1	S6	-16.4 - -19.5
106	-9.1 - -9.4	S8	-20.4 - -23.5
107	-7.9 - -8.5	S9	-11.0 - -14.1
108	-25.0 - -28.0	S11a	1.5 - -3.4
SDW	-21.3 - -25.3	S11b	-21.9 - -25.0
f- Fred C. Hart (1982)		S11c	-29.9 - -33.0

Site& Well	El. of screened interval	Site& Well	El. of screened interval
RES (a)		Shell&	
R	-4.3 - -4.9	Pureland (b)	
U	0.7 - -0.03	10A	-36.6 - -51.8
DP1	-22.8 - -25.8	10B	-36.3 - -51.5
DP2	-21.9 - -24.9	6A	-36.3 - -51.5
~~DP3~~	-16.1 - -19.1	6B	-27.4 - -42.7
DP4	-21.6 - -24.6	6C	-22.2 - -38.7
		8A	-36.3 - -51.5
		WT1	0.3 - -0.3
		WT2	0.6 - -2.0
		WT3	-1.6 - -2.2
		WT4	-1.2 - -1.8
		L3	-90.8 - -103.3
		L4	-38.1 - -56.4

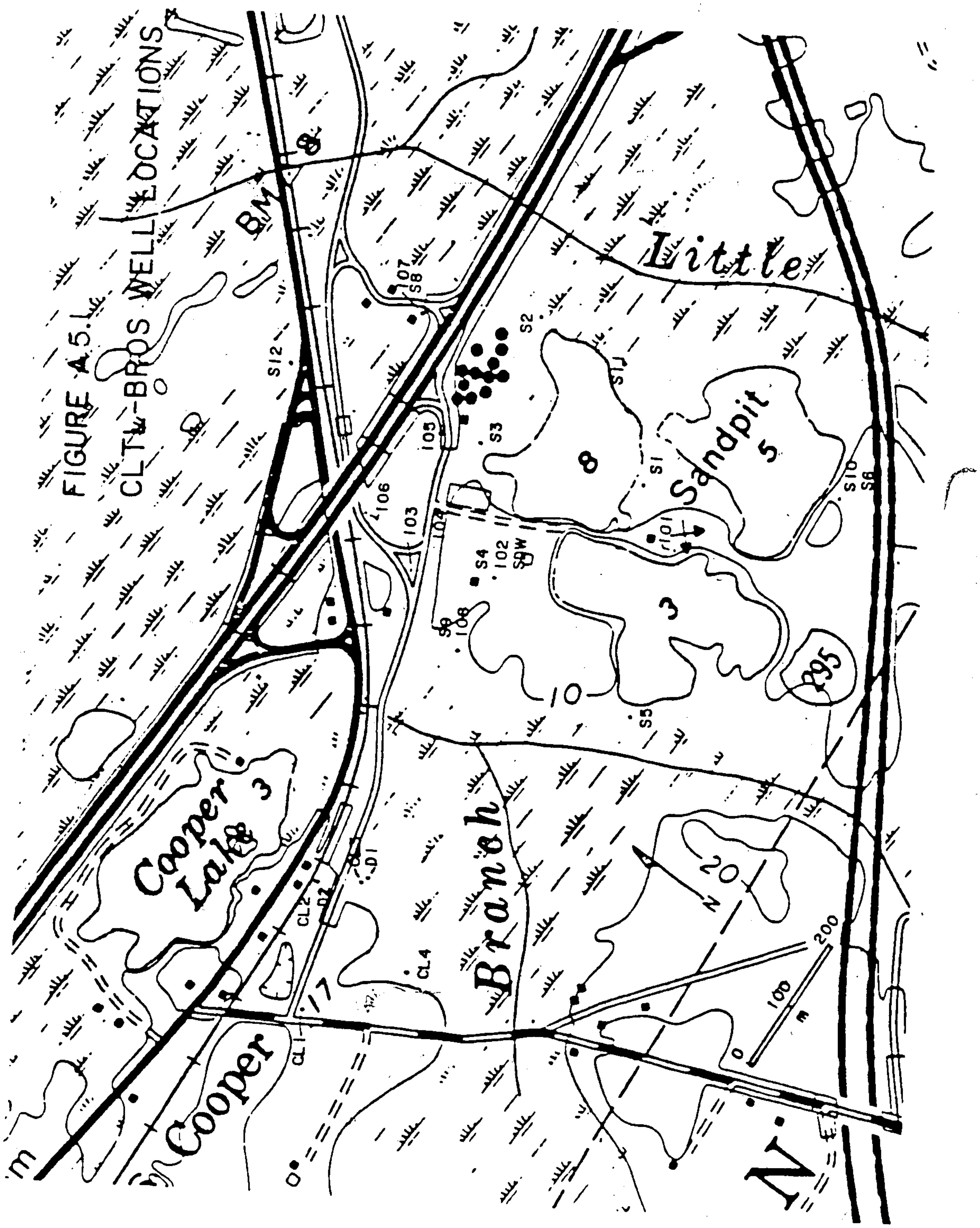


FIGURE A5.1
CLTL-BROS WELL LOCATIONS
Little
Sandpit
Cooper Lake
Branch
Cooper
BM
S1
S2
S3
S4
S5
S6
S8
S10
S11
S12
101
102
103
104
105
106
107
108
CL1
CL2
CL4
D1
D2
SDW
295
0
100
200
N

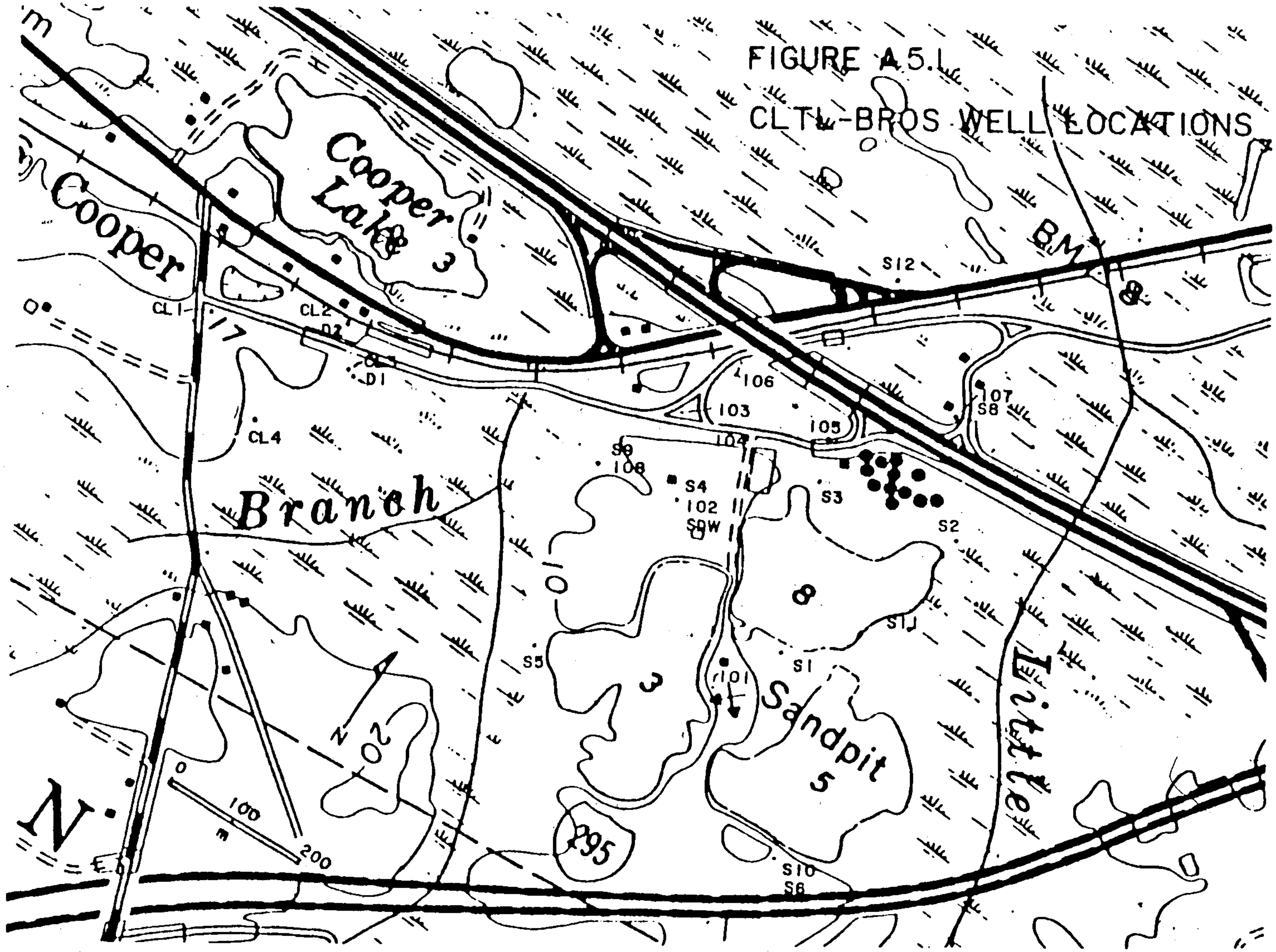


FIGURE A5.1

CLTL-BROS WELL LOCATIONS

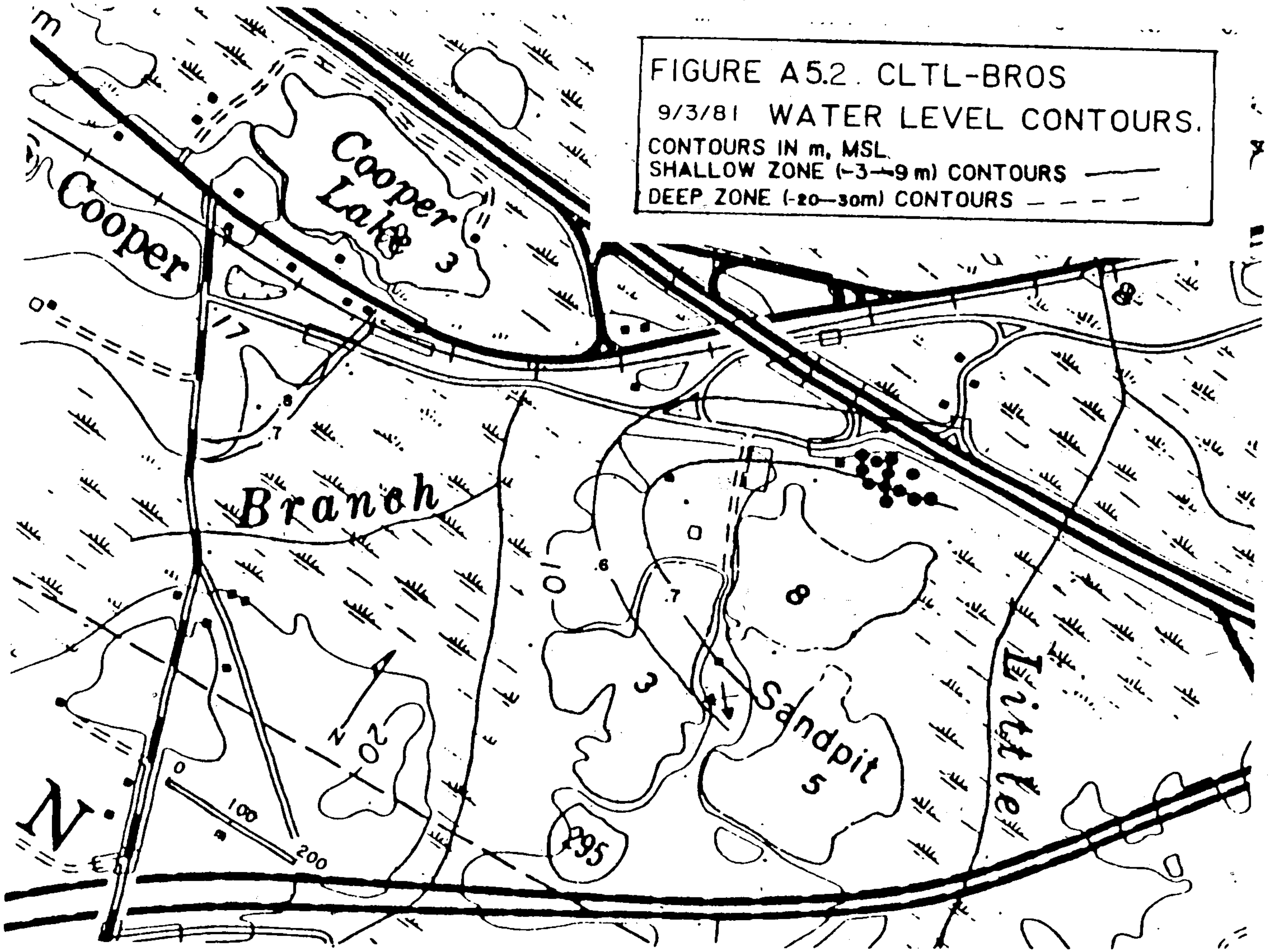


FIGURE A5.2. CLTL-BROS
9/3/81 WATER LEVEL CONTOURS.

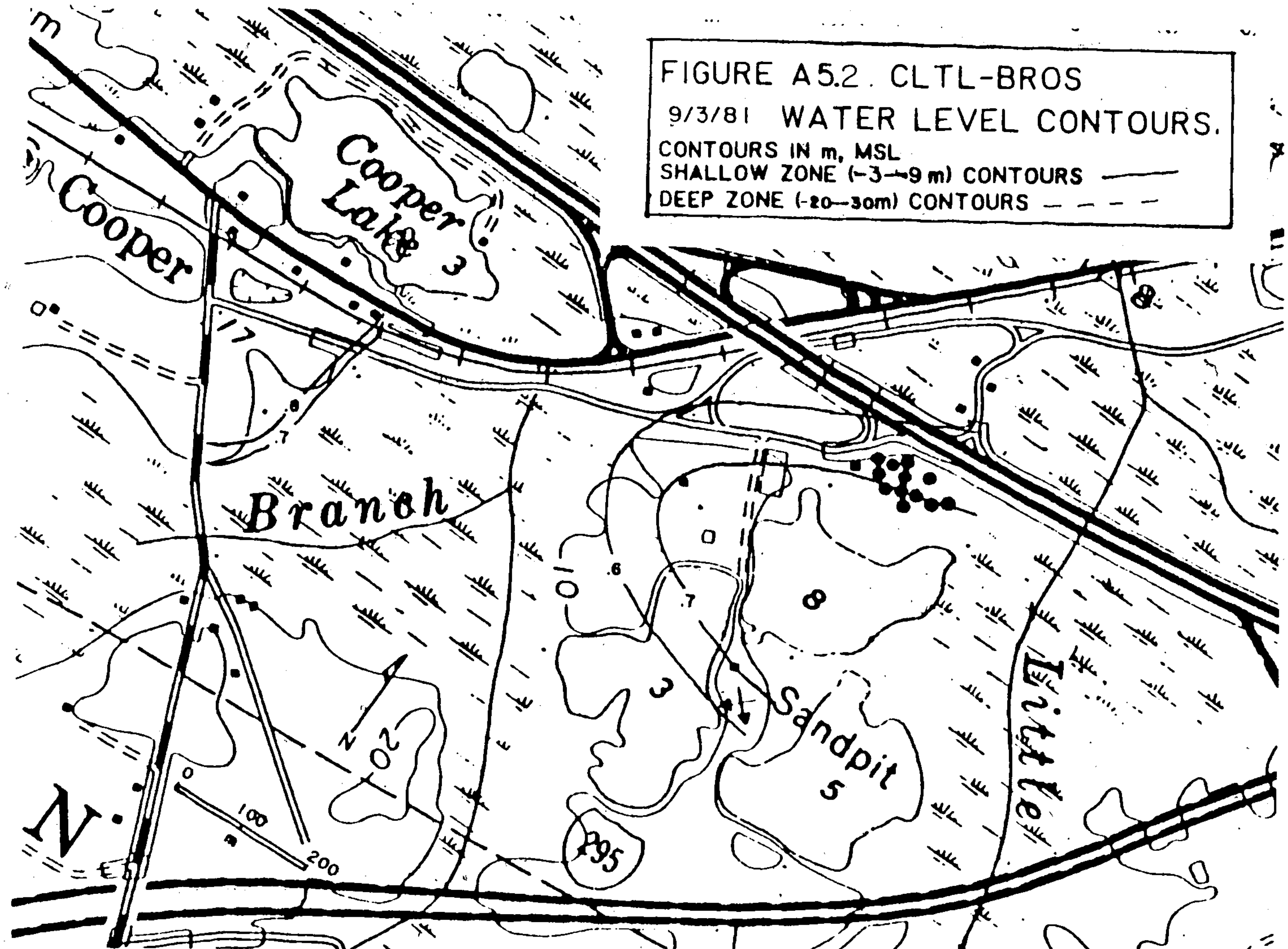


FIGURE A5.2. CLTL-BROS
9/3/81 WATER LEVEL CONTOURS.
CONTOURS IN m, MSL
SHALLOW ZONE (-3—9 m) CONTOURS ———
DEEP ZONE (-20—30m) CONTOURS – – – –

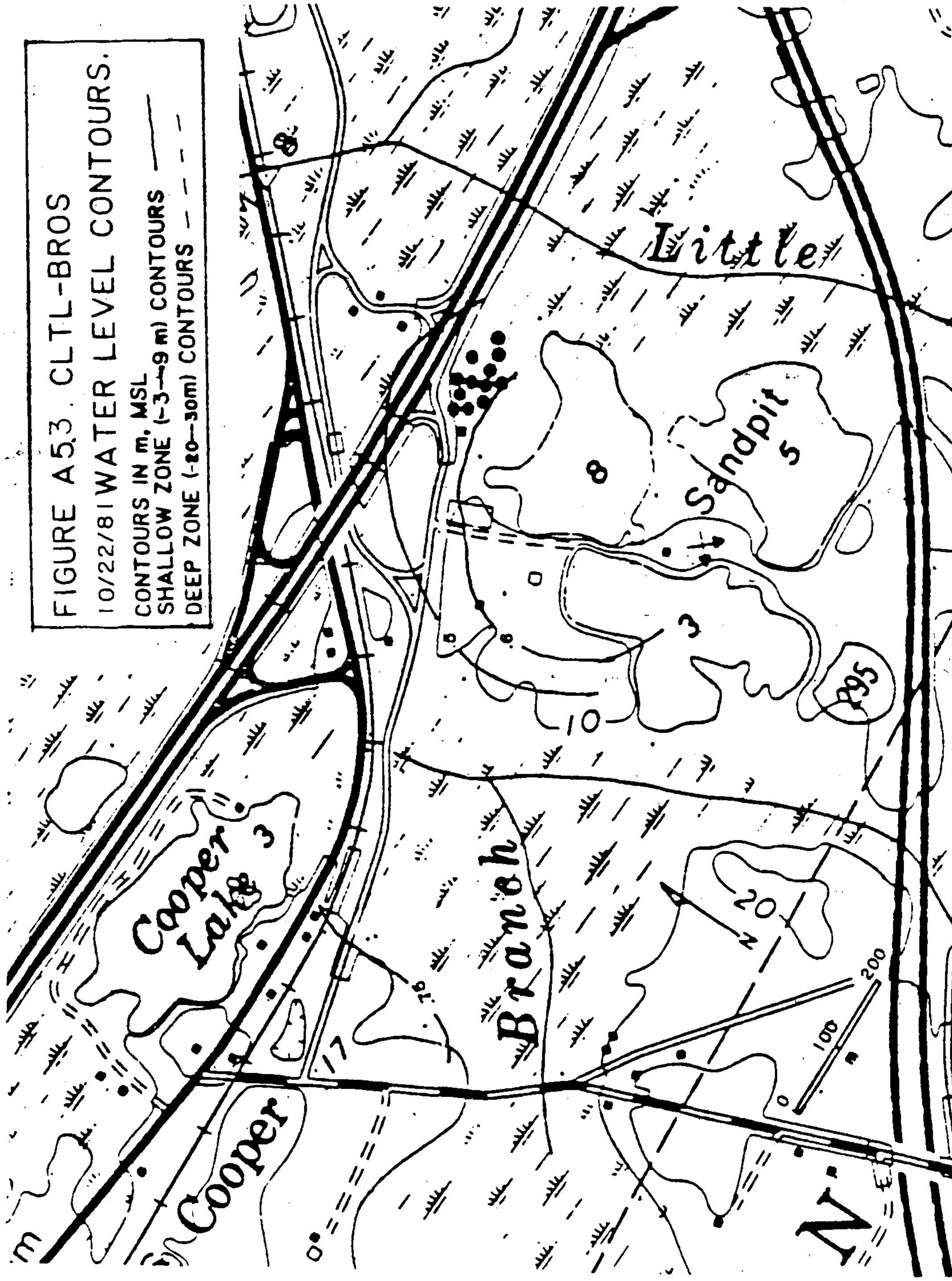


FIGURE A53. CLTL-BROS
10/22/81 WATER LEVEL CONTOURS.

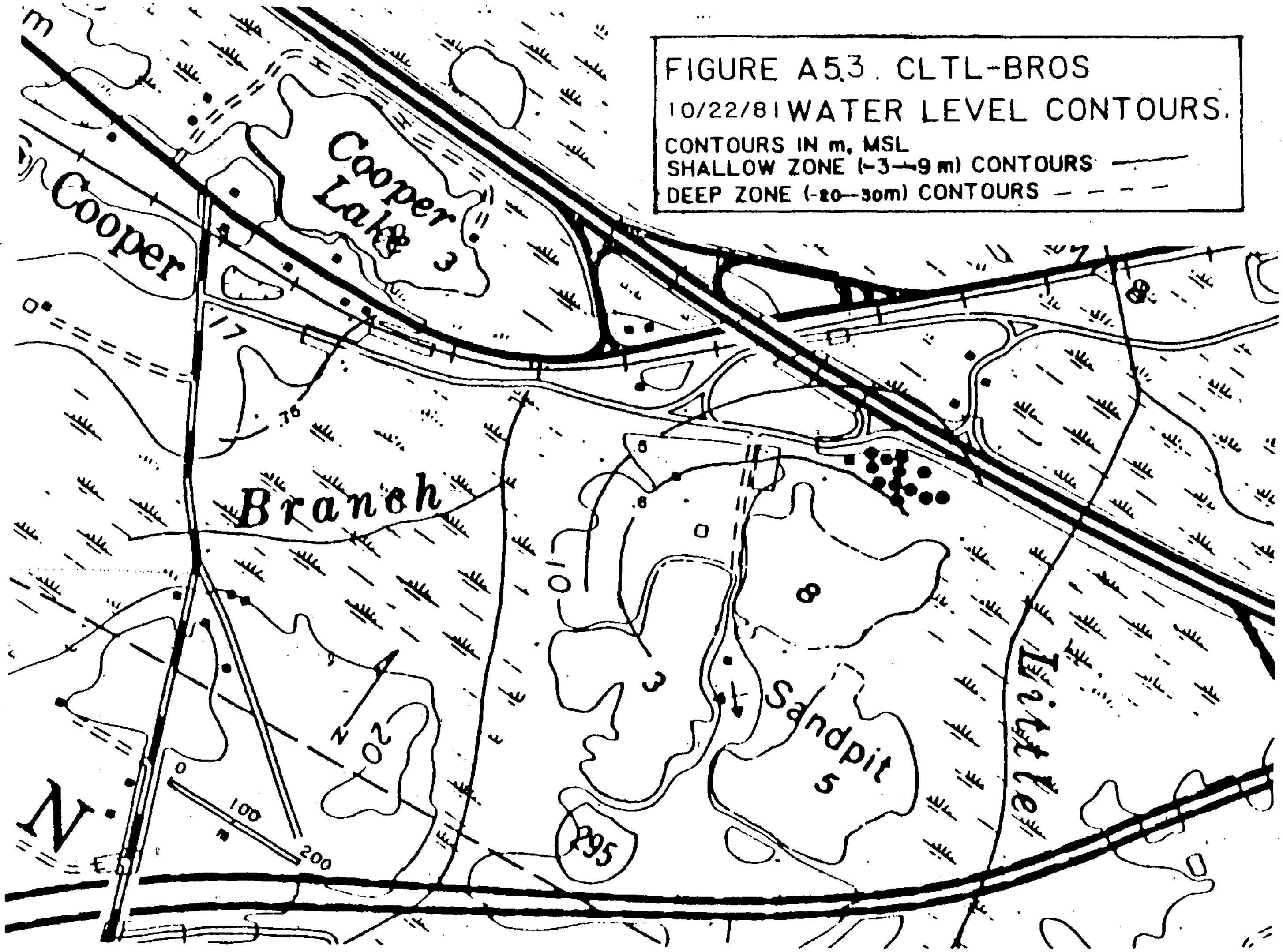


FIGURE A53. CLTL-BROS
10/22/81 WATER LEVEL CONTOURS.
CONTOURS IN m, MSL
SHALLOW ZONE (-3—-9 m) CONTOURS
DEEP ZONE (-20—-30m) CONTOURS

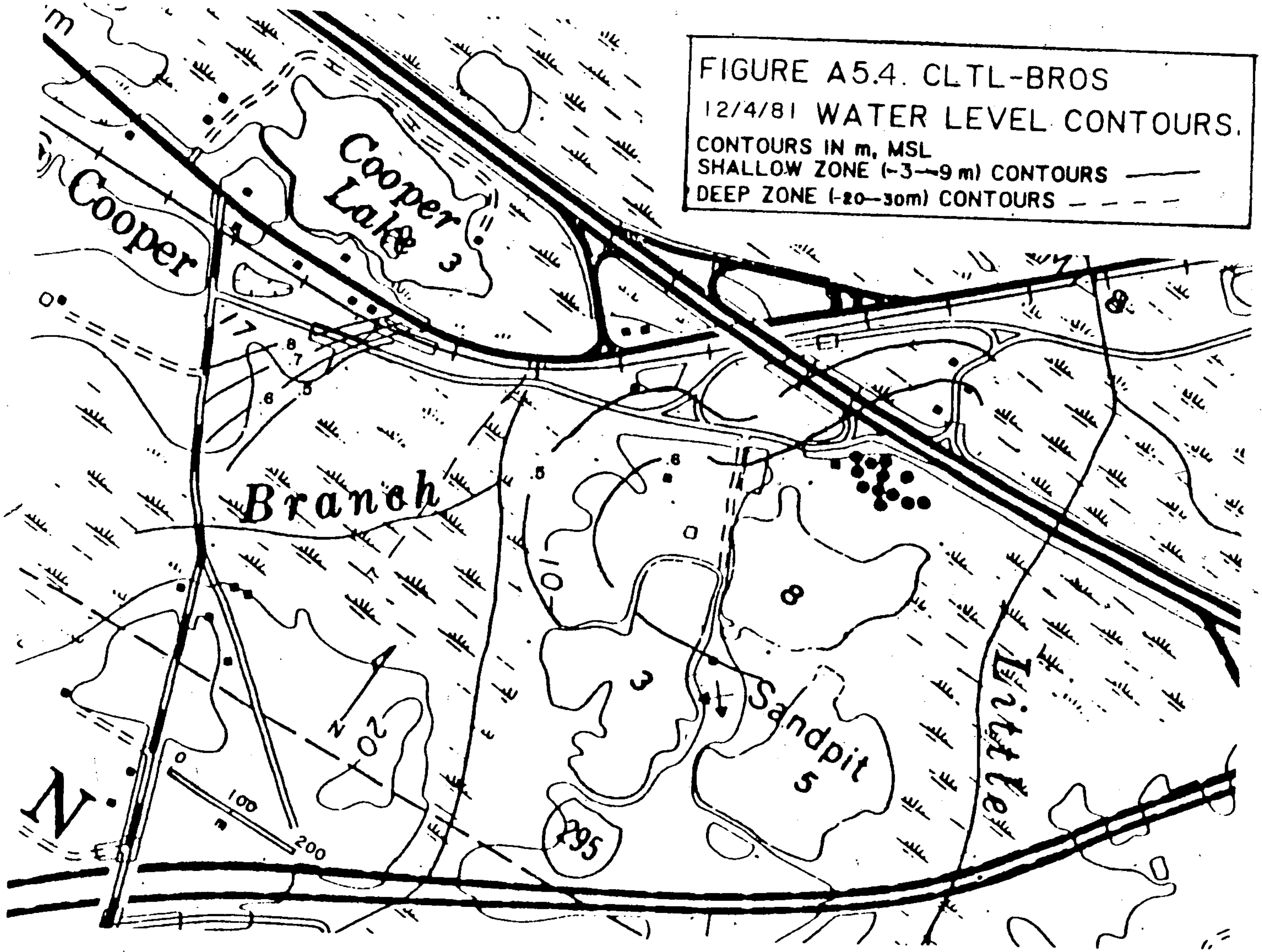


FIGURE A5.4. CLTL-BROS
12/4/81 WATER LEVEL CONTOURS.
CONTOURS IN m, MSL
SHALLOW ZONE (-3—-9 m) CONTOURS ———
DEEP ZONE (-20—-30m) CONTOURS — — — —

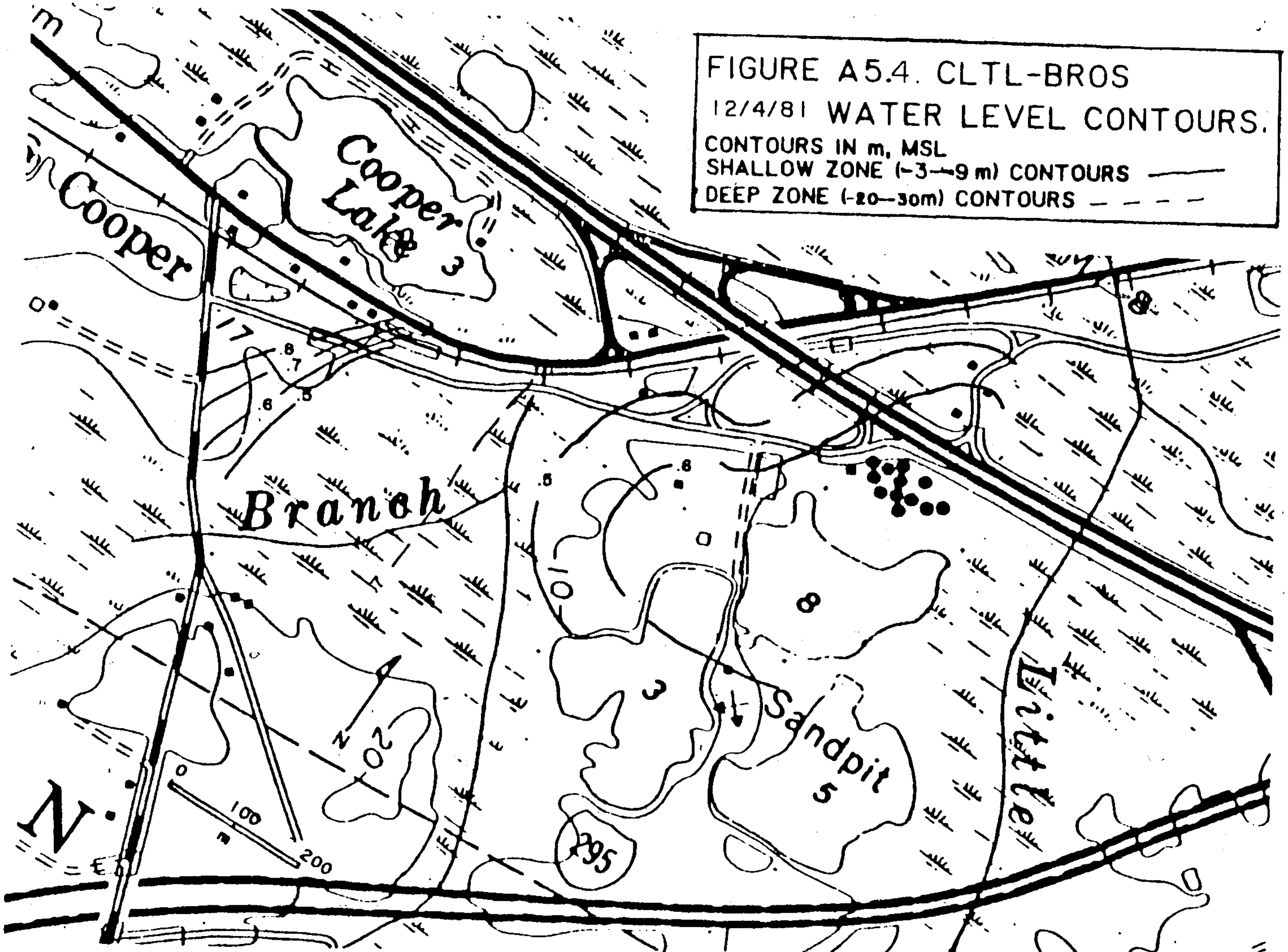


FIGURE A5.4. CLTL-BROS
12/4/81 WATER LEVEL CONTOURS.
CONTOURS IN m, MSL
SHALLOW ZONE (-3—-9 m) CONTOURS ———
DEEP ZONE (-20—-30m) CONTOURS - - - -

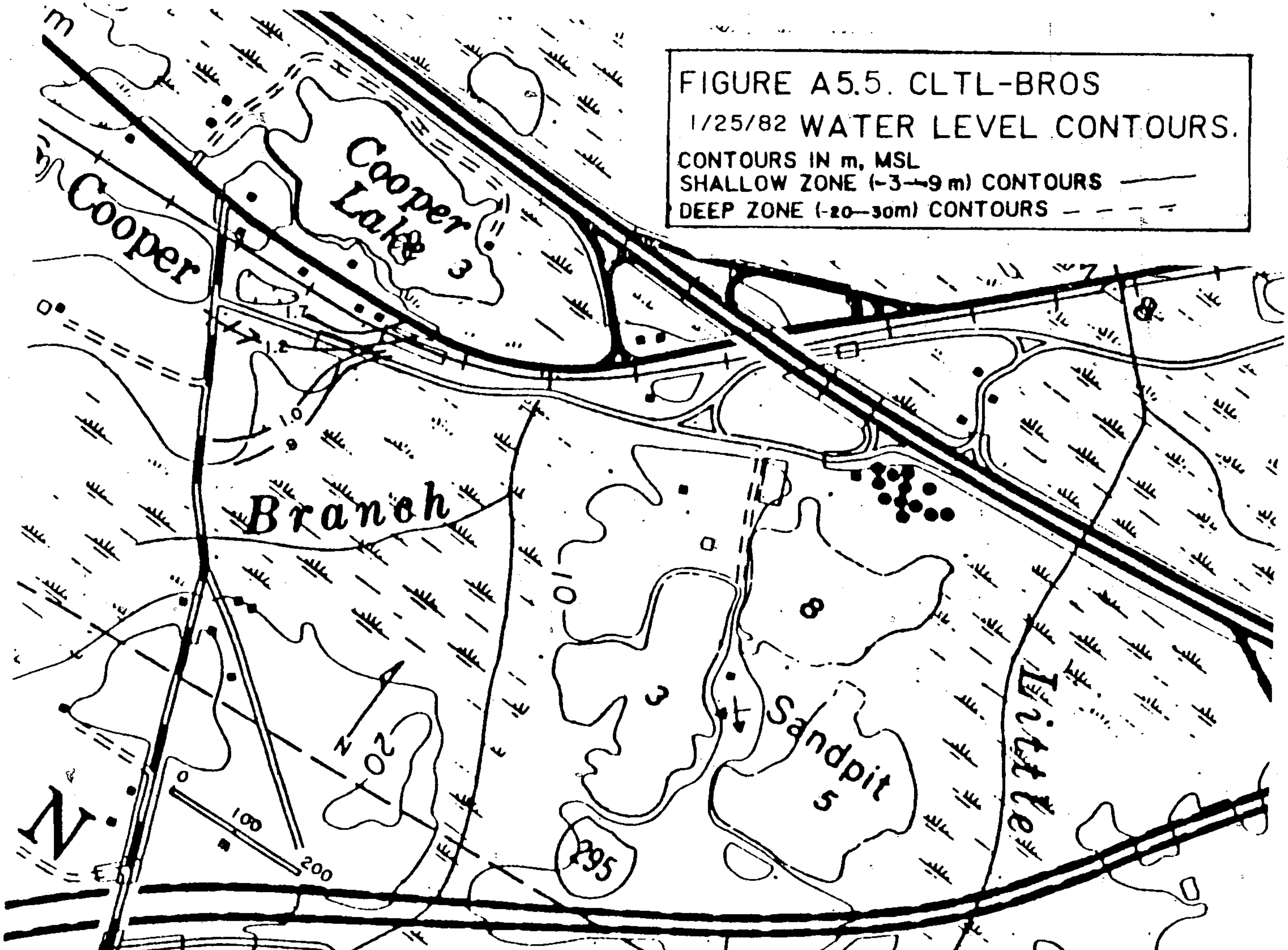


FIGURE A5.5. CLTL-BROS
1/25/82 WATER LEVEL CONTOURS.

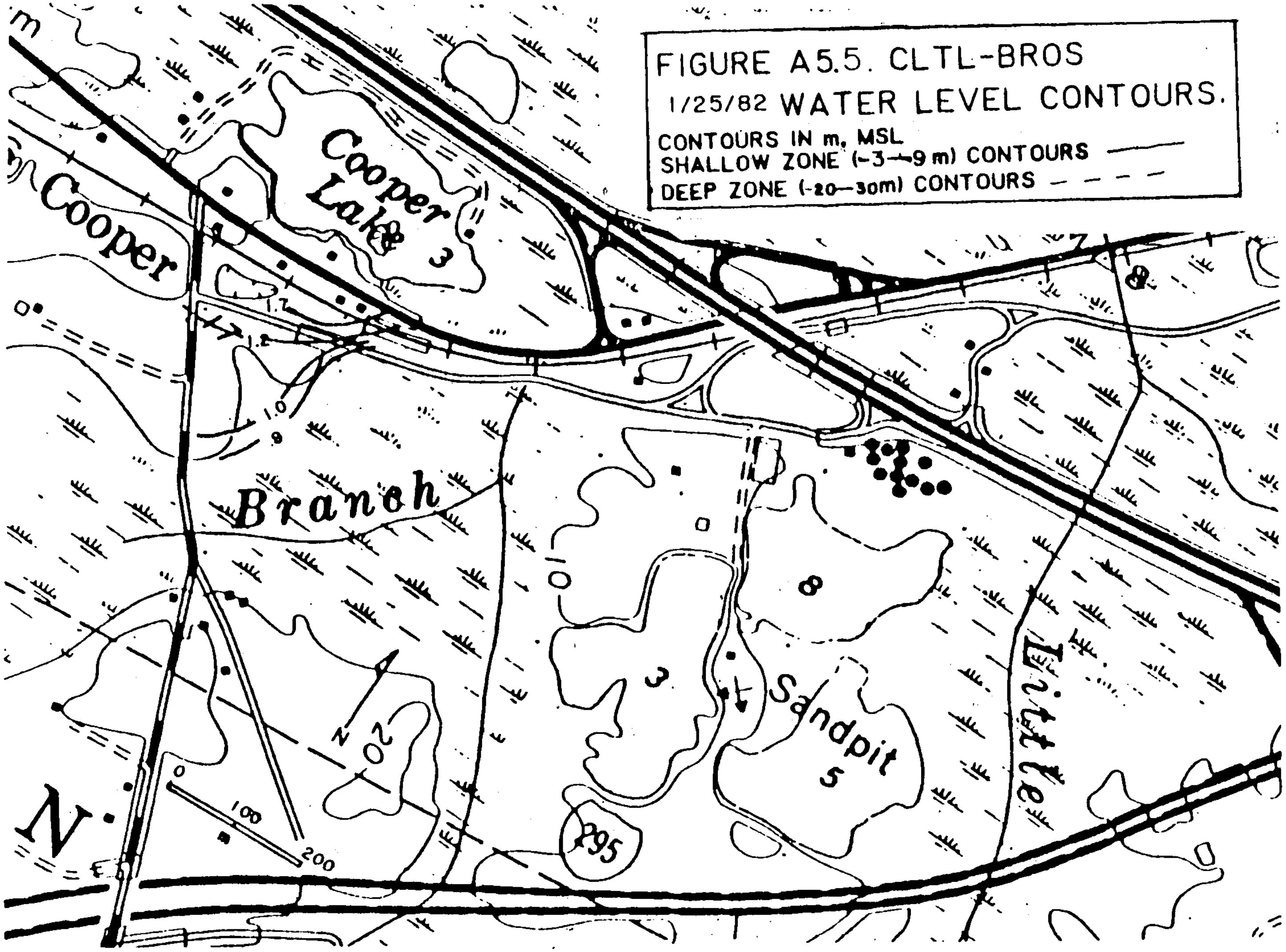
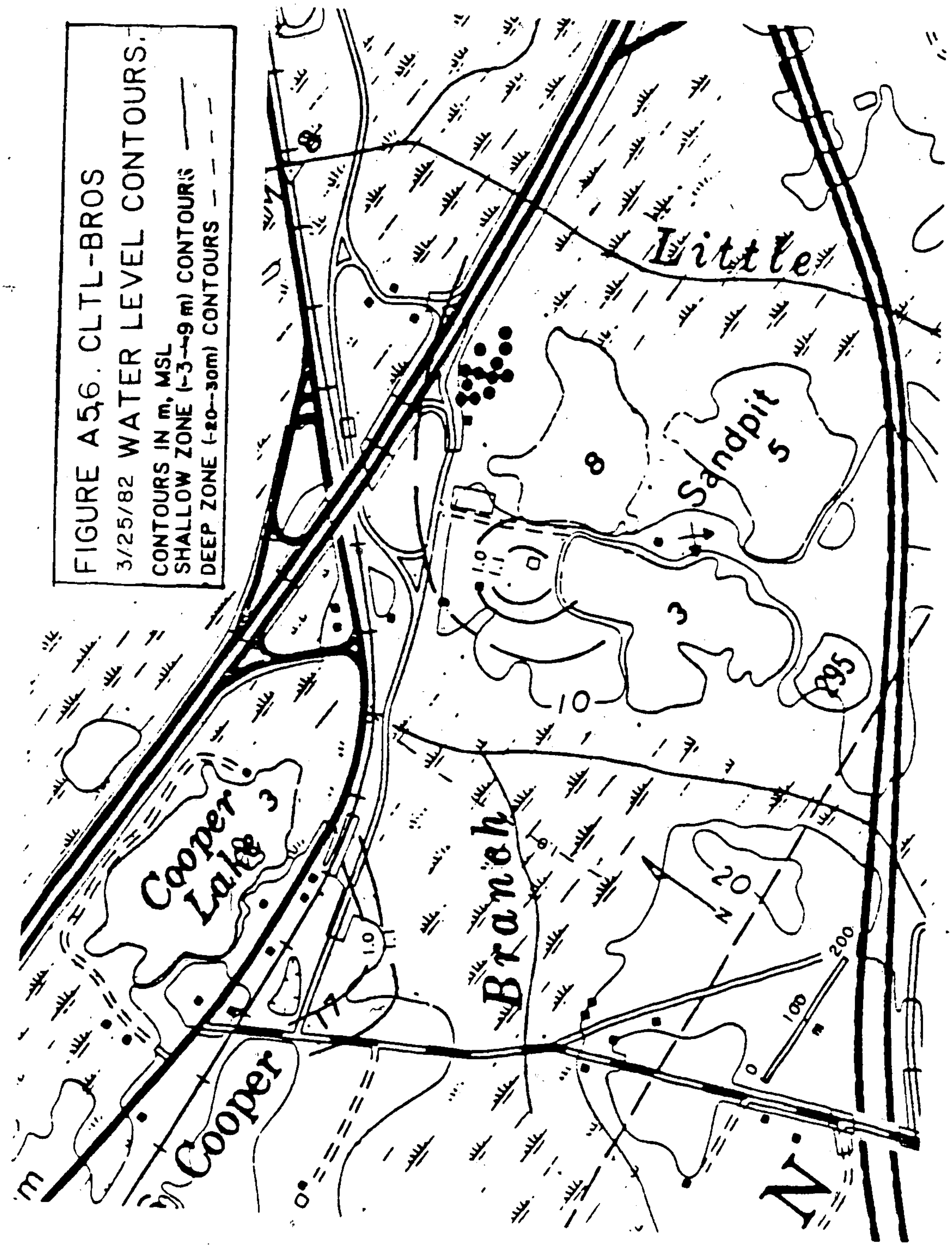


FIGURE A5.5. CLTL-BROS
1/25/82 WATER LEVEL CONTOURS.
CONTOURS IN m, MSL
SHALLOW ZONE (-3—9 m) CONTOURS
DEEP ZONE (-20—30m) CONTOURS

FIGURE A5.6. CLTL-BROS
3/25/82 WATER LEVEL CONTOURS.
CONTOURS IN m, MSL
SHALLOW ZONE (-3—-9 m) CONTOURS ———
DEEP ZONE (-20—-30m) CONTOURS — — —



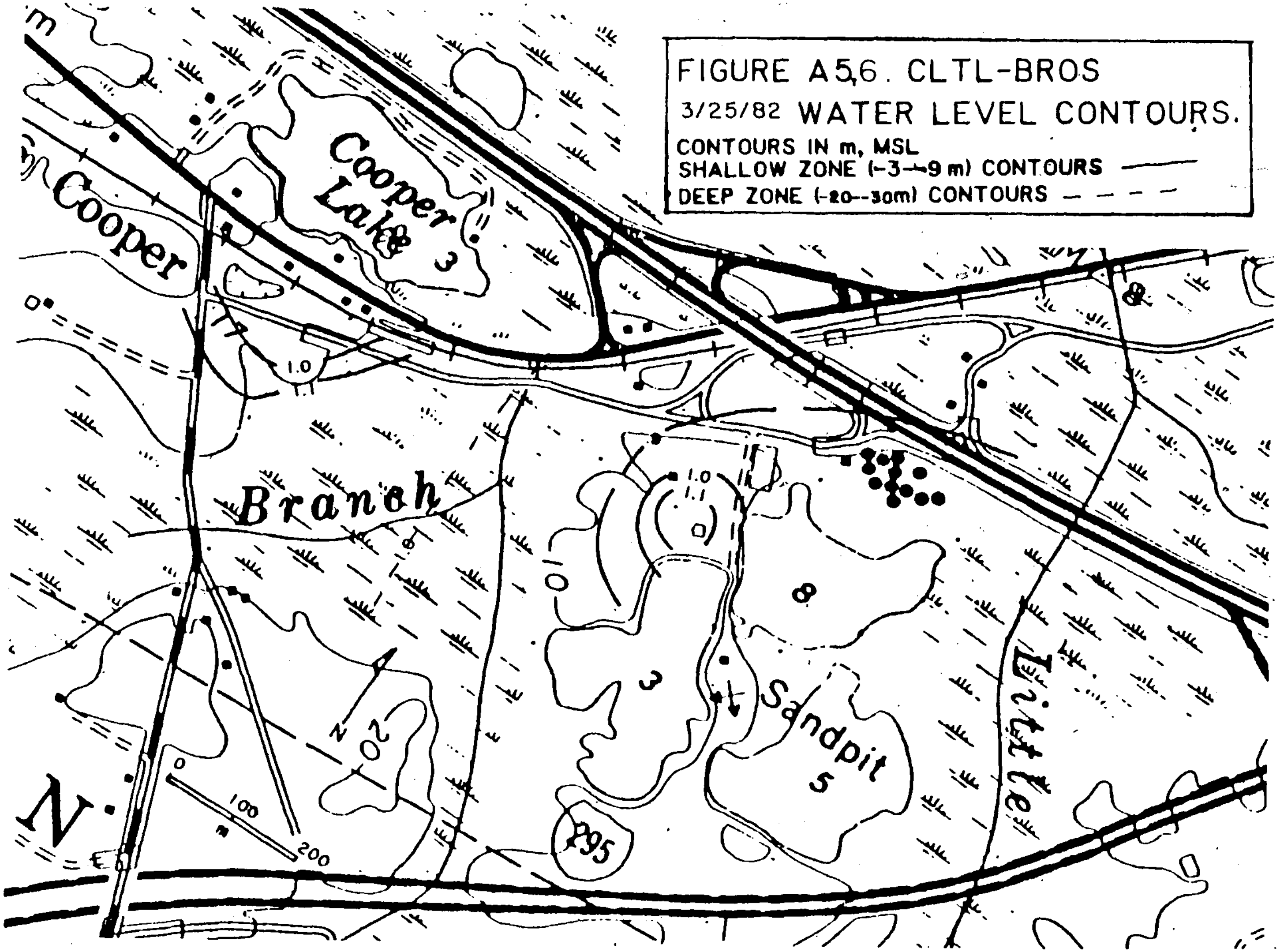


FIGURE A5.6. CLTL-BROS
3/25/82 WATER LEVEL CONTOURS.
CONTOURS IN m, MSL
SHALLOW ZONE (-3--9 m) CONTOURS ———
DEEP ZONE (-20--30m) CONTOURS — — — —

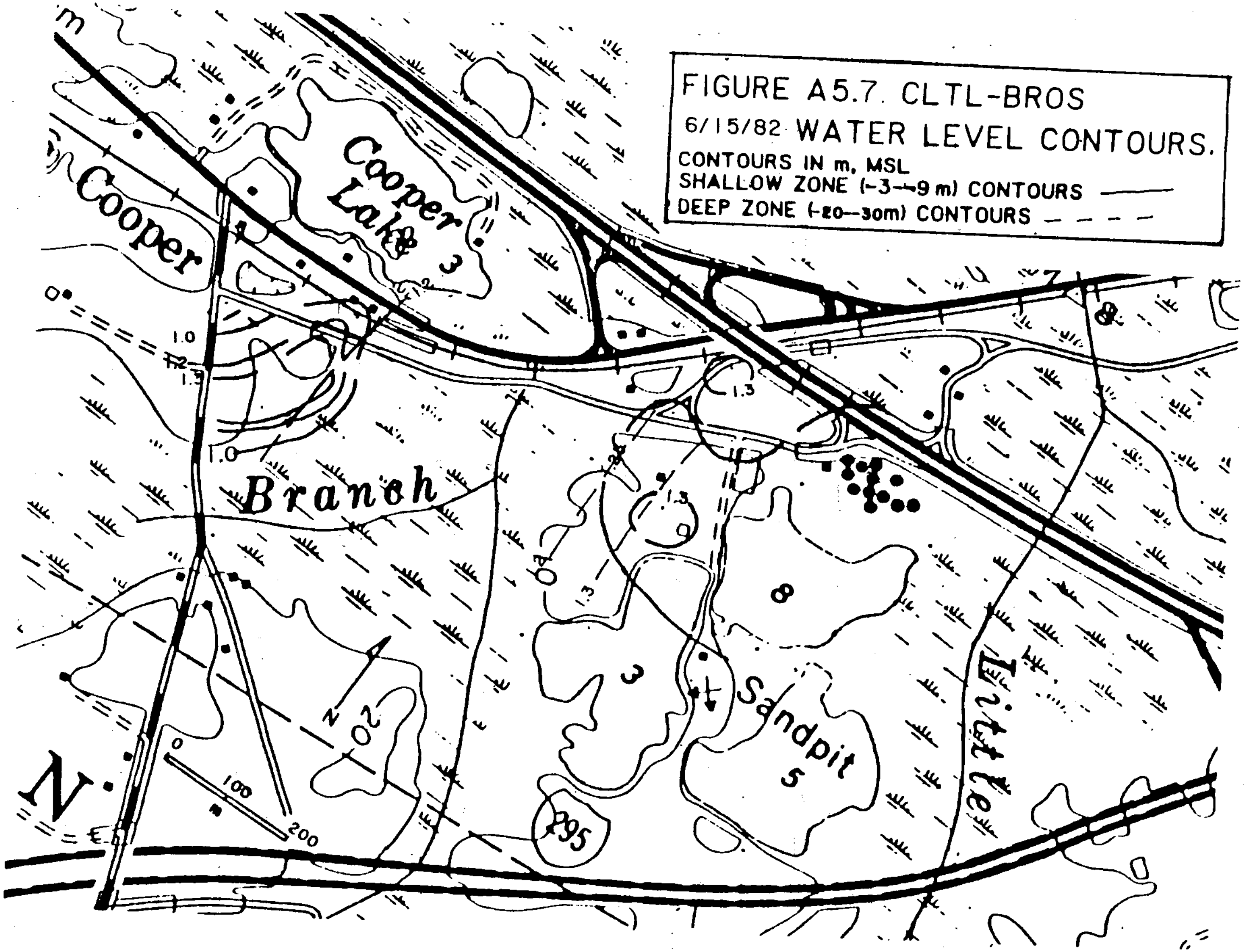


FIGURE A5.7. CLTL-BROS
6/15/82 WATER LEVEL CONTOURS.
CONTOURS IN m, MSL
SHALLOW ZONE (-3--9 m) CONTOURS ———
DEEP ZONE (-20--30m) CONTOURS — — — —

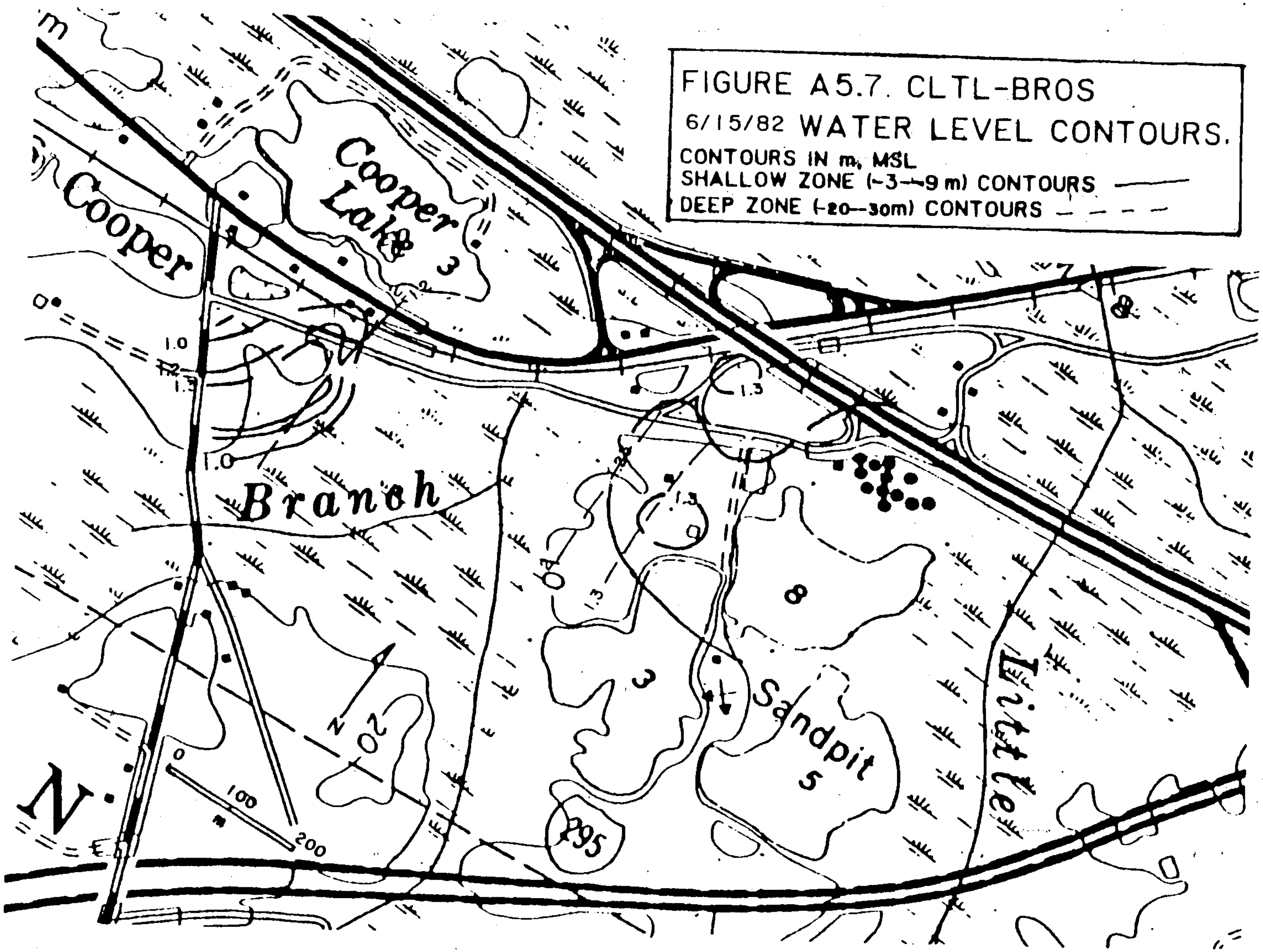


FIGURE A5.7. CLTL-BROS
6/15/82 WATER LEVEL CONTOURS.
CONTOURS IN m, MSL
SHALLOW ZONE (-3--9 m) CONTOURS
DEEP ZONE (-20--30m) CONTOURS

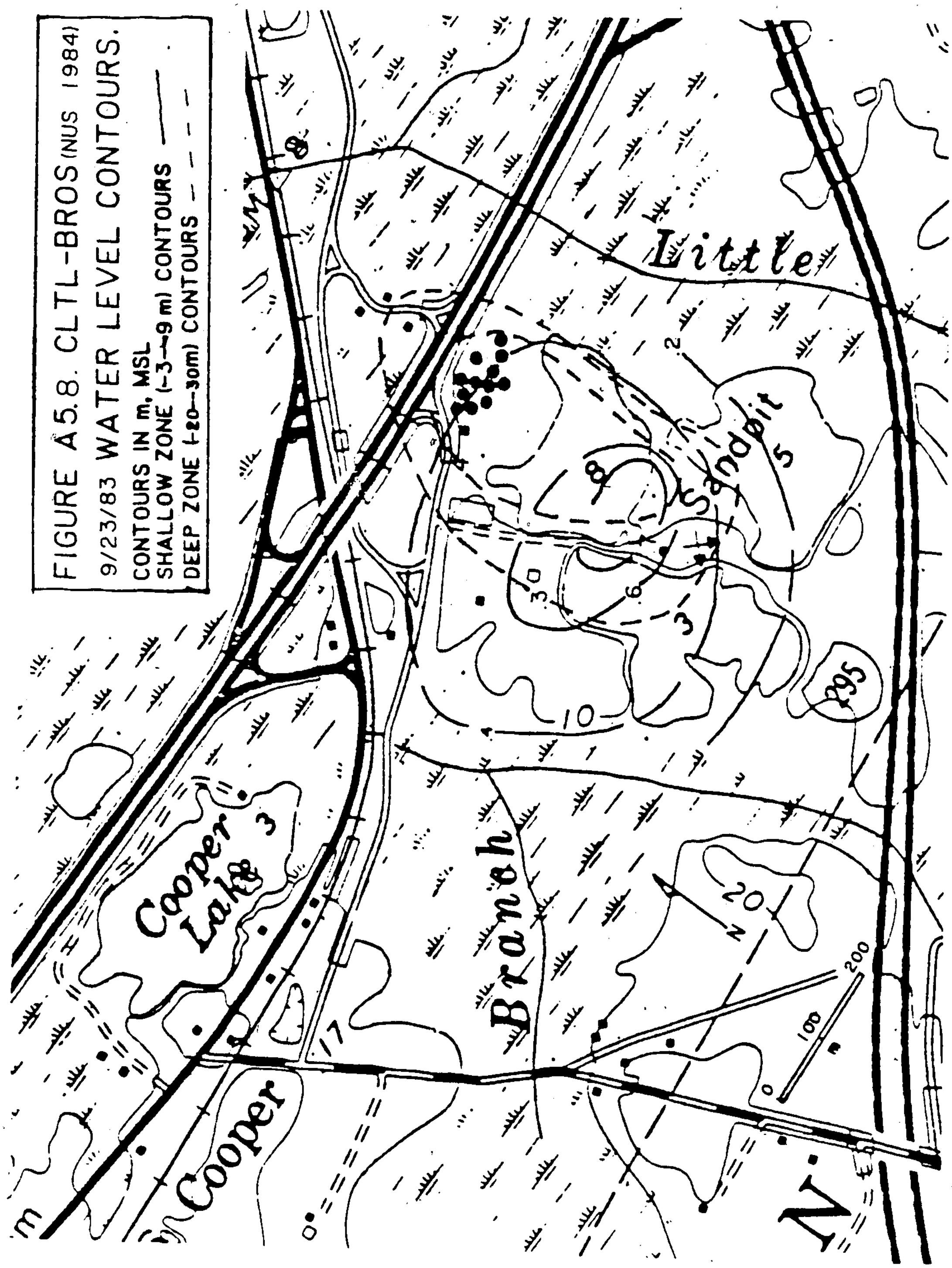


FIGURE A5.8. CLTL-BROS (NUS 1984)
9/23/83 WATER LEVEL CONTOURS.
CONTOURS IN m, MSL
SHALLOW ZONE (-3—-9 m) CONTOURS ———
DEEP ZONE (-20—-30m) CONTOURS — — —

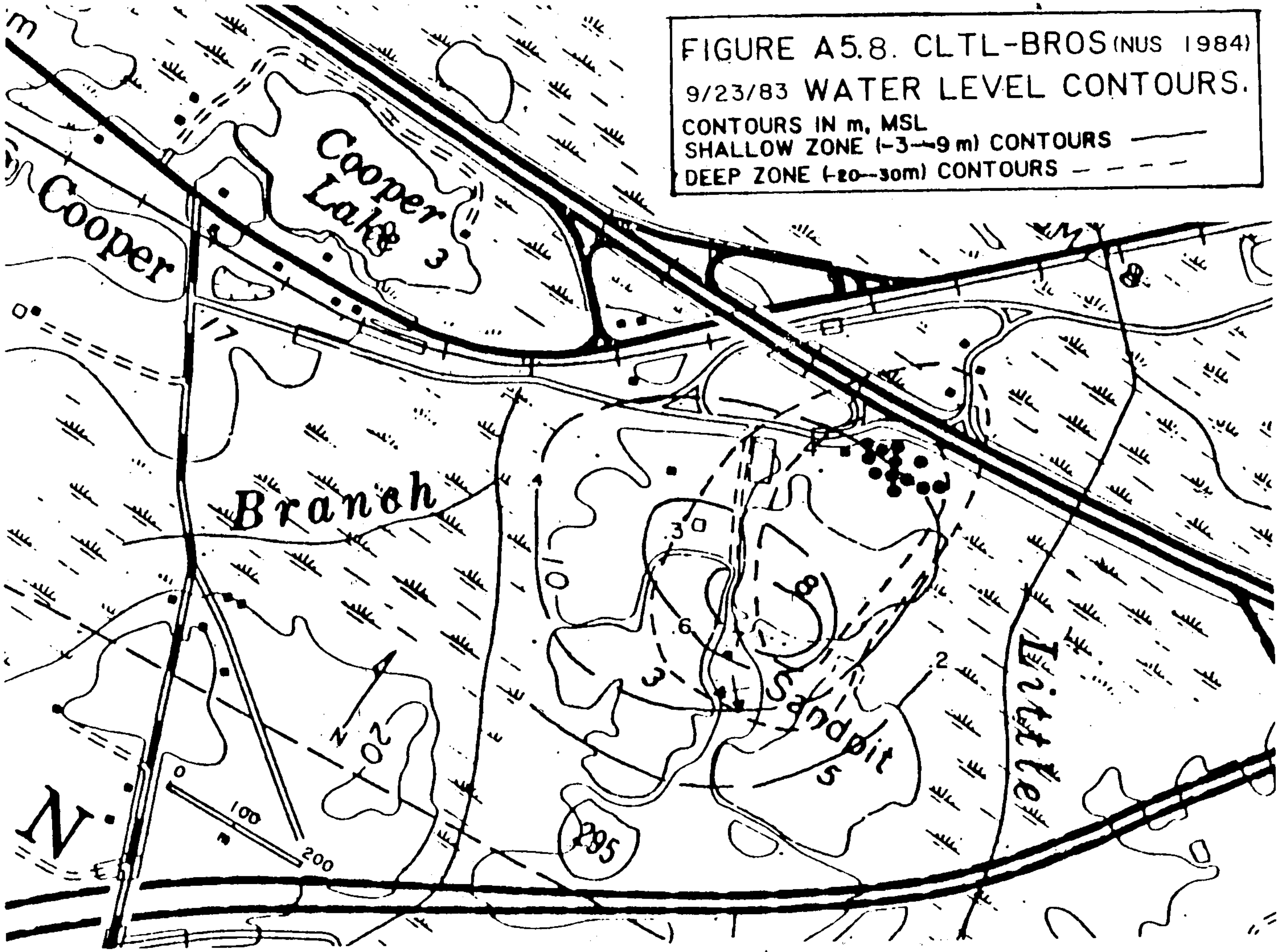


FIGURE A5.8. CLTL-BROS (NUS 1984)
9/23/83 WATER LEVEL CONTOURS.
CONTOURS IN m, MSL
SHALLOW ZONE (-3--9 m) CONTOURS ———
DEEP ZONE (-20--30m) CONTOURS - - - -

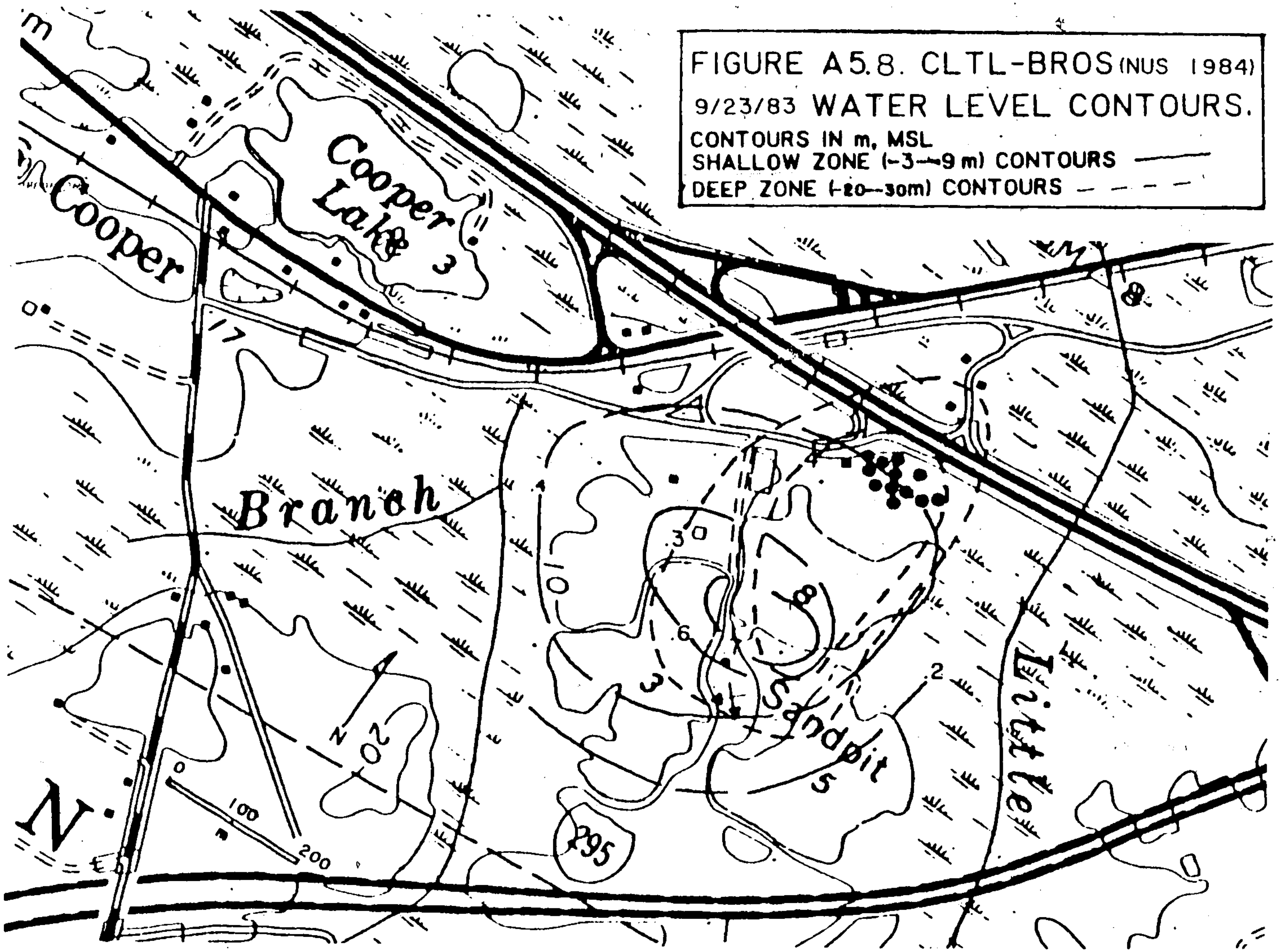


FIGURE A5.8. CLTL-BROS (NUS 1984) 9/23/83 WATER LEVEL CONTOURS.

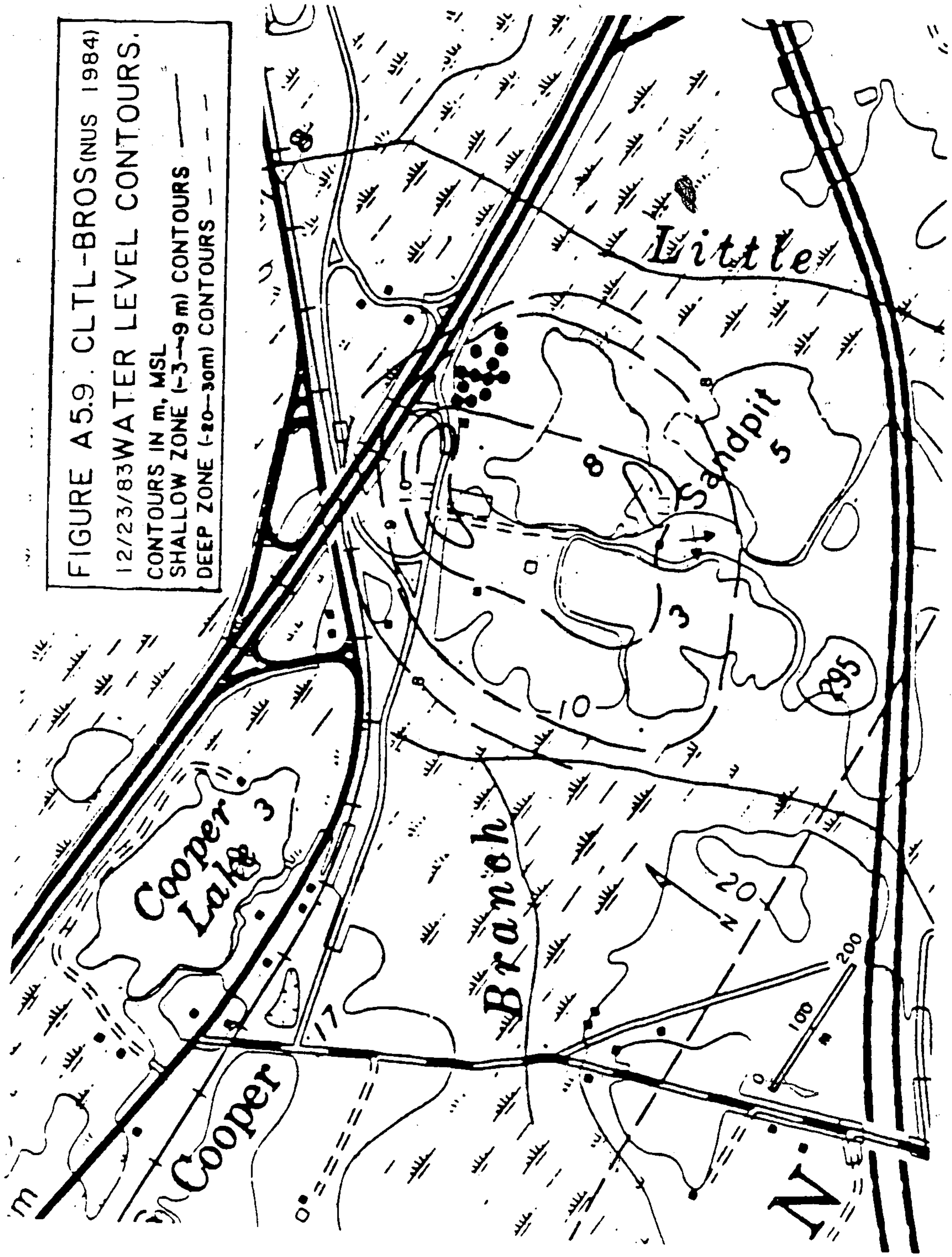


FIGURE A5.9. CLTL-BROS (NUS 1984)
12/23/83 WATER LEVEL CONTOURS.
CONTOURS IN m, MSL
SHALLOW ZONE (-3—-9 m) CONTOURS
DEEP ZONE (-20—-30m) CONTOURS

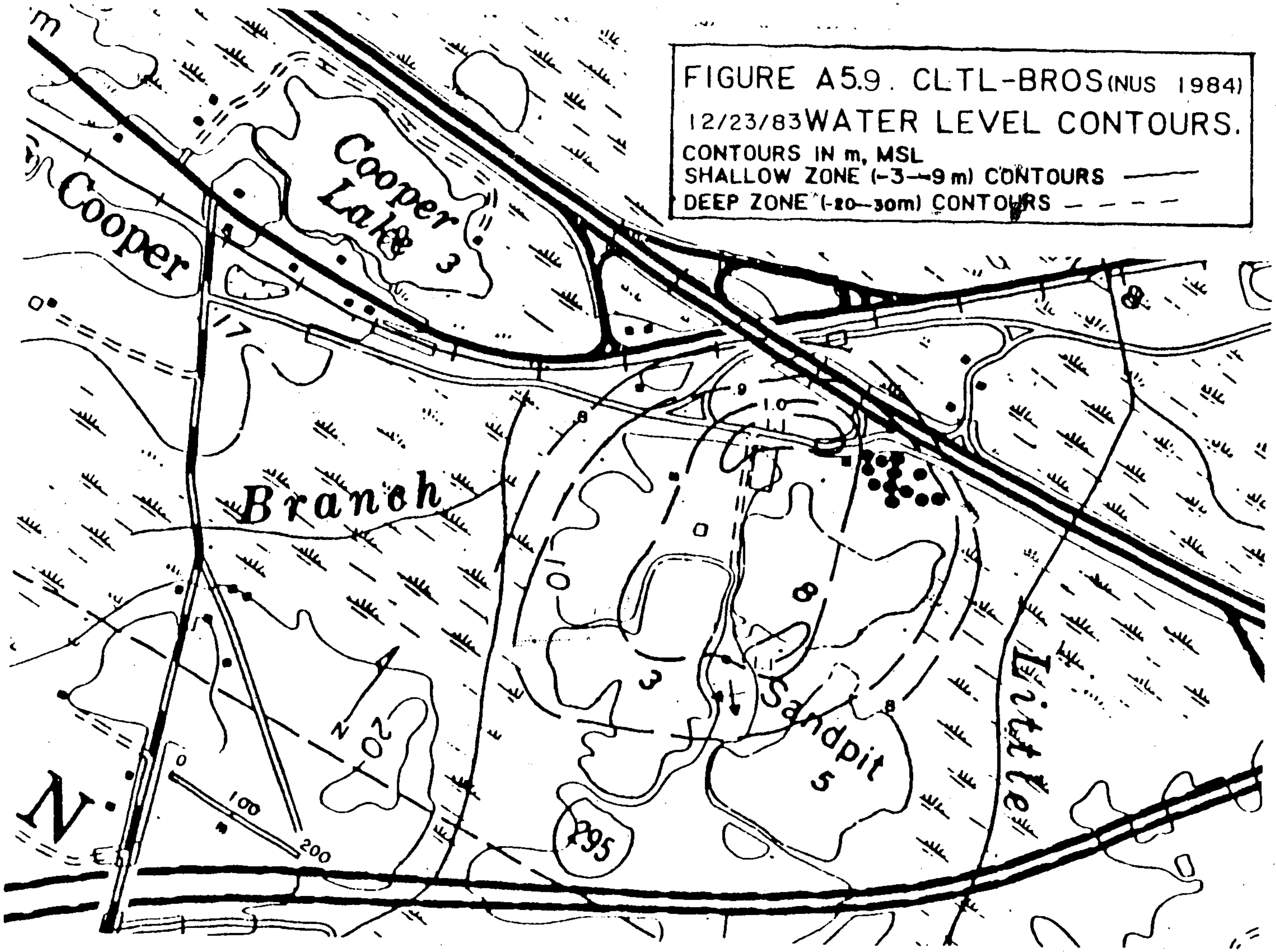


FIGURE A5.9. CLTL-BROS(NUS 1984)
12/23/83 WATER LEVEL CONTOURS.
CONTOURS IN m, MSL
SHALLOW ZONE (-3—9 m) CONTOURS
DEEP ZONE (-20—30m) CONTOURS
Cooper Lake 3
Cooper
Branch
Sandpit 5
Little
295
N
0
100
200
1.0
.9
.8

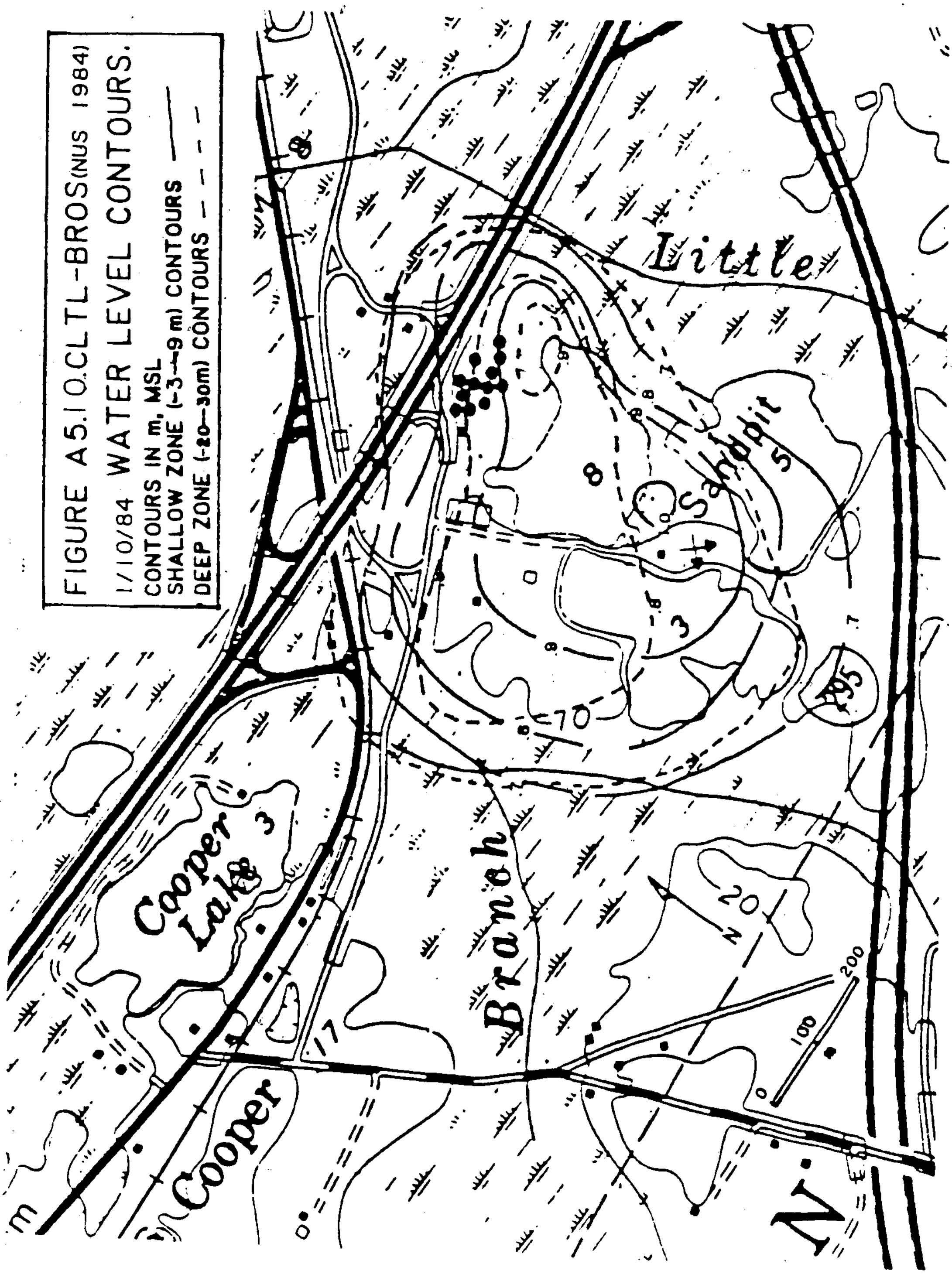


FIGURE A5.10.CLTL-BROS(NUS 1984)
1/10/84 WATER LEVEL CONTOURS.
CONTOURS IN m, MSL
SHALLOW ZONE (-3—-9 m) CONTOURS ———
DEEP ZONE (-20—-30m) CONTOURS — — —

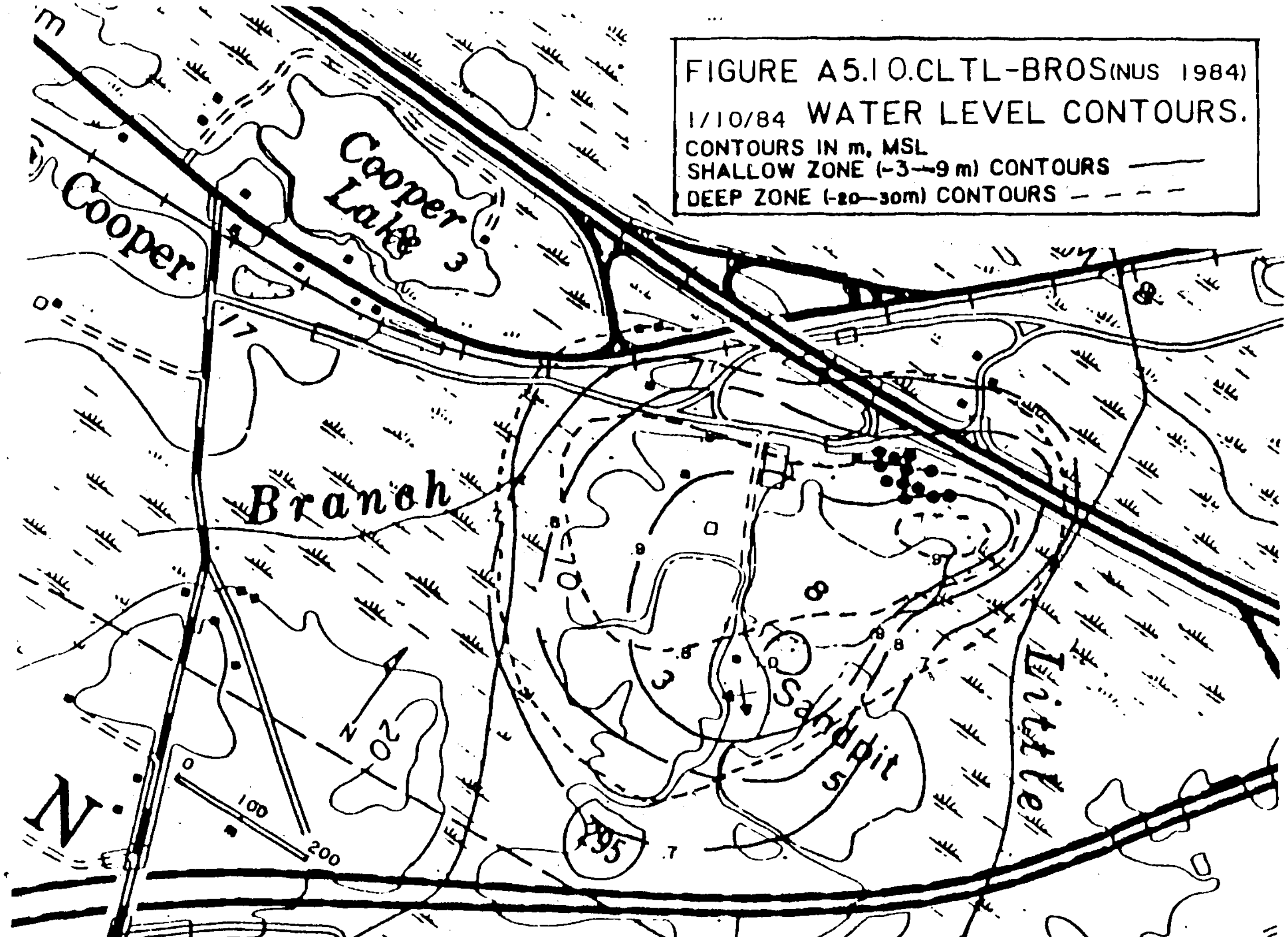


FIGURE A5.10.CLTL-BROS(NUS 1984)
1/10/84 WATER LEVEL CONTOURS.
CONTOURS IN m, MSL
SHALLOW ZONE (-3—9 m) CONTOURS
DEEP ZONE (-20—30m) CONTOURS

Figure A5.11a RES Well Hydrographs. From Geraghty and Miller (1982).

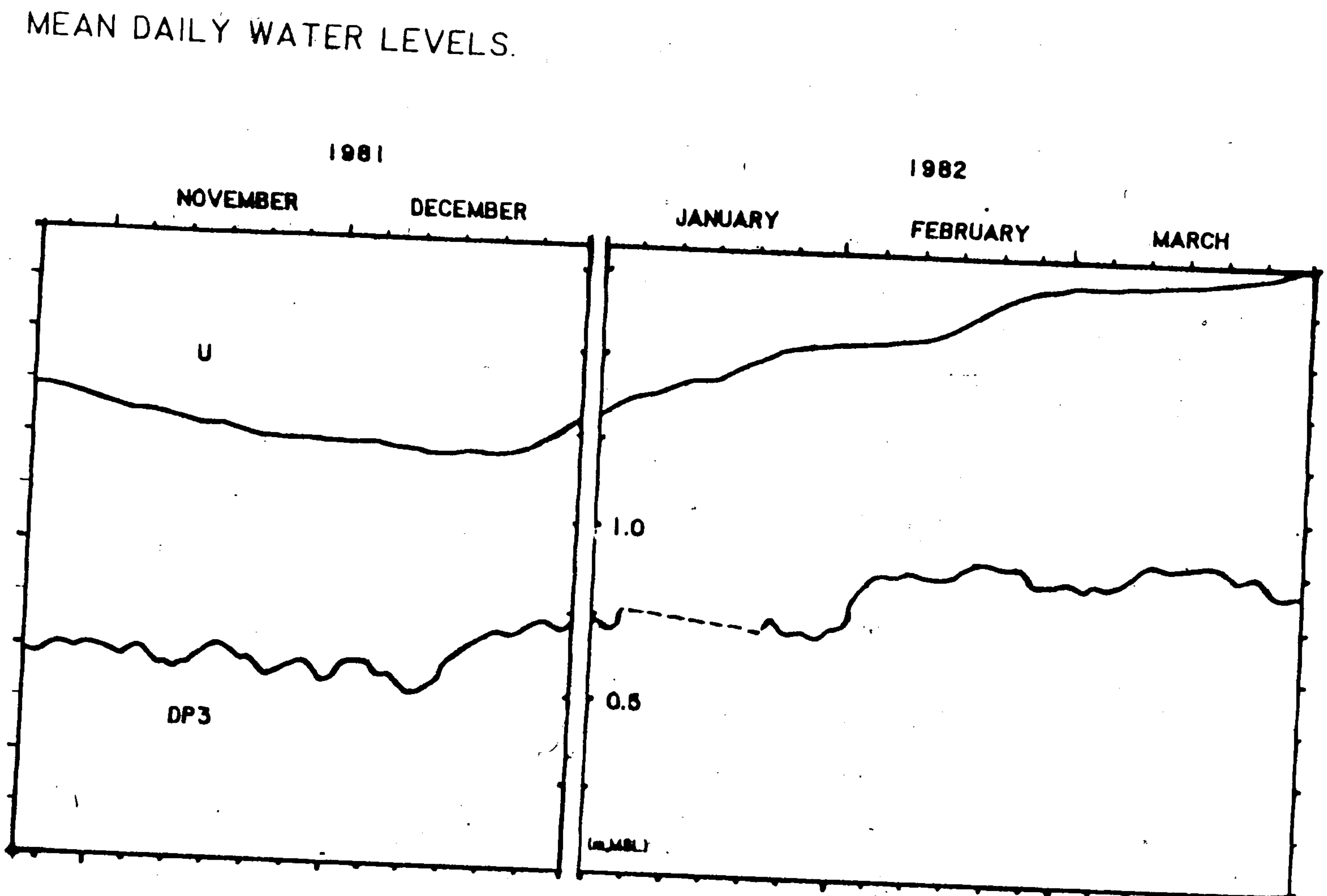


Figure A5.11a RES Well Hydrographs. From Geraghty and Miller (1982).

MEAN DAILY WATER LEVELS.

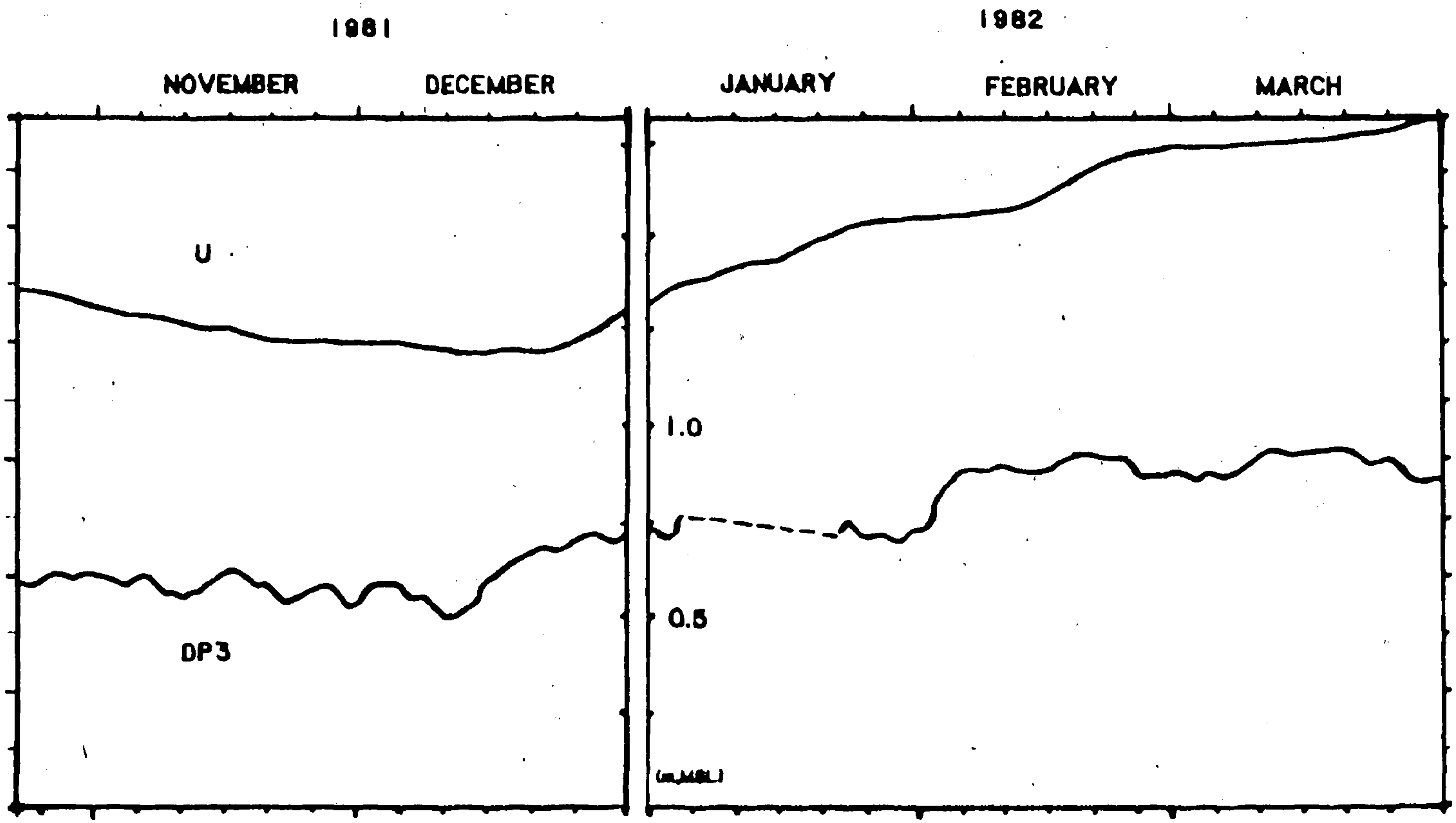


Figure A5.11b RES Well Hydrographs. From Geraghty and Miller (1982).

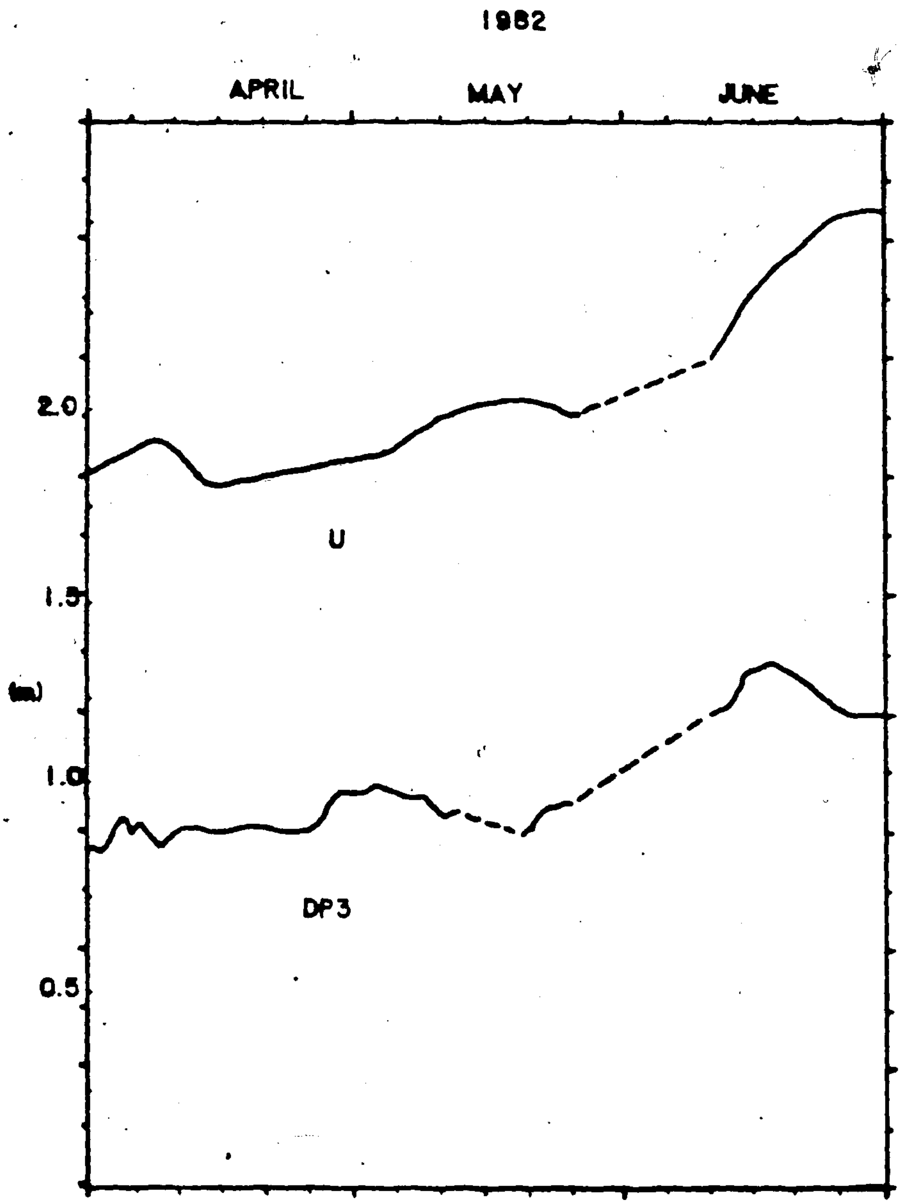
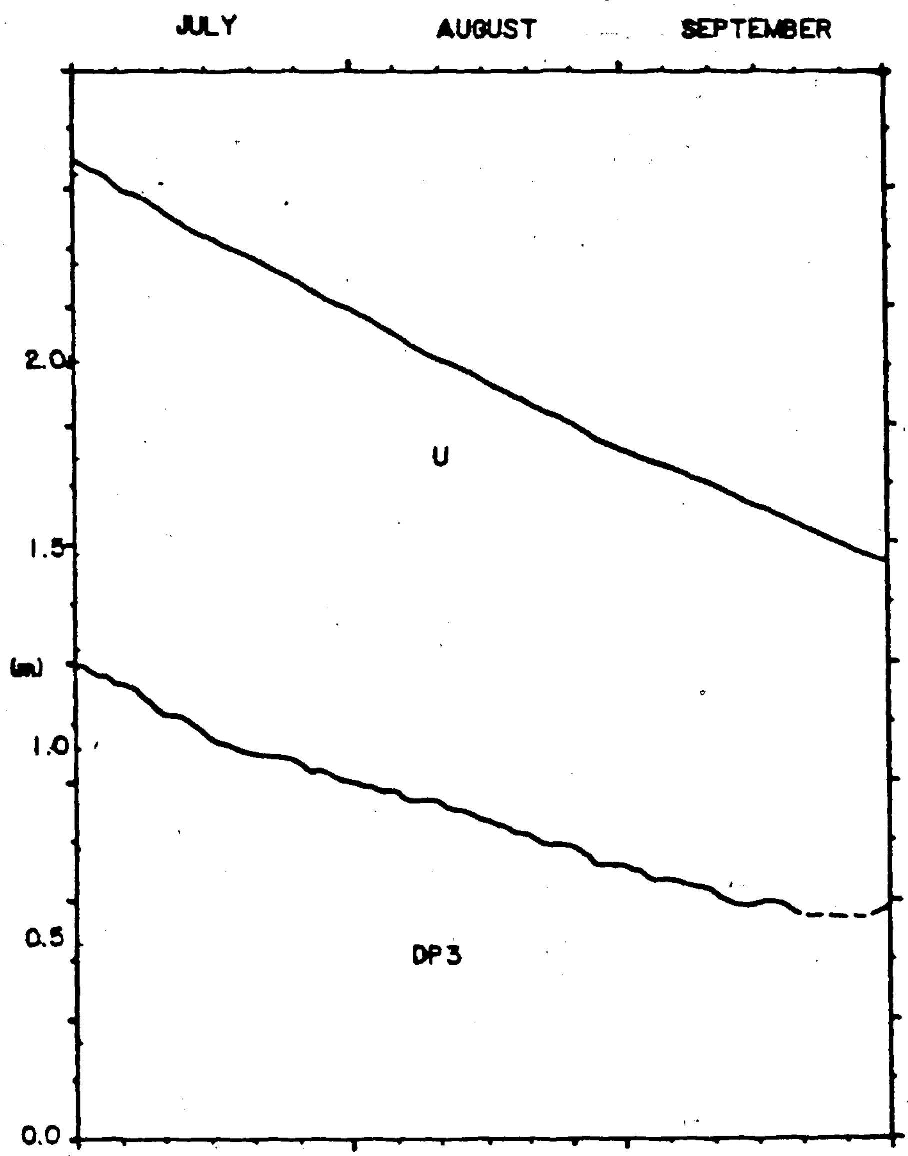


Figure A5.11c RES Well Hydrographs. From Geraghty and Miller (1982).



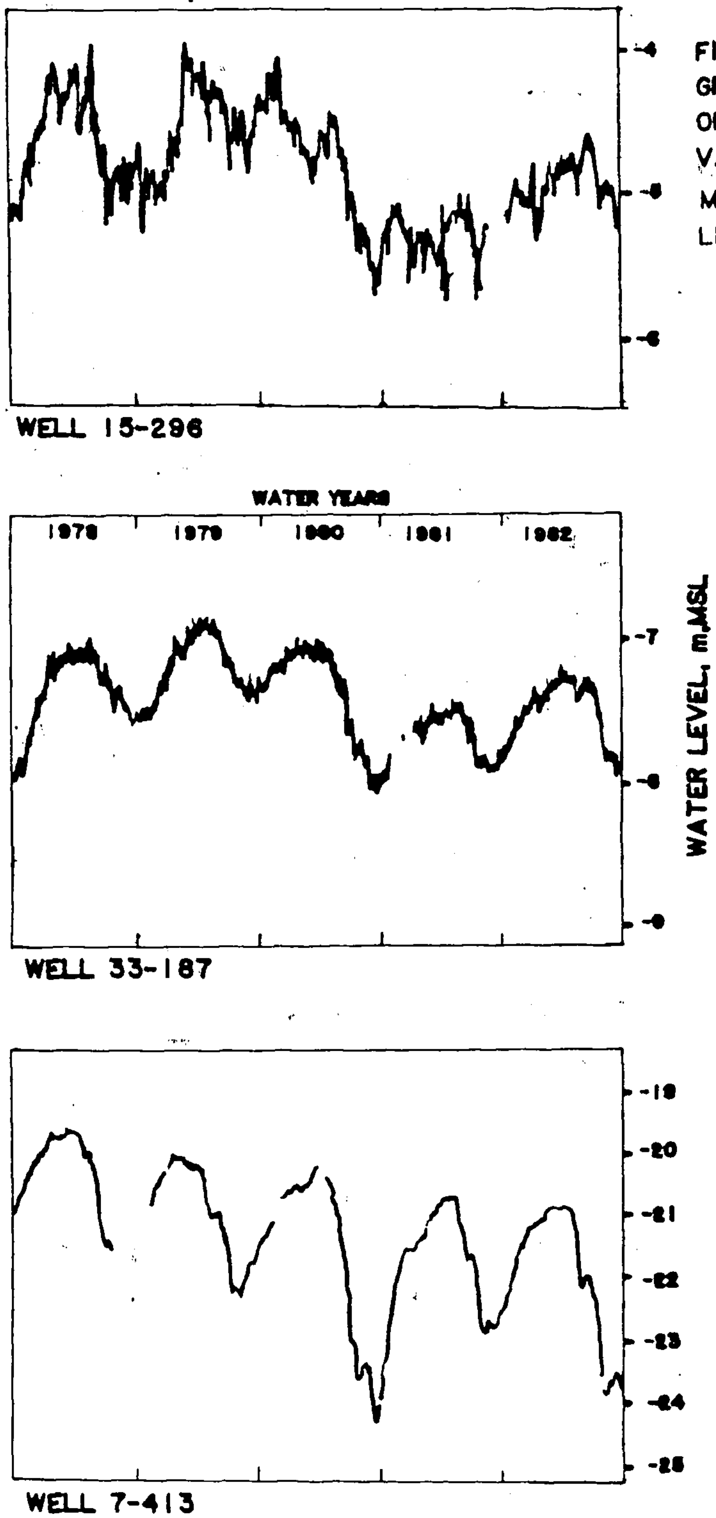


FIGURE A5.12 WELL HYDROGRAPHS FROM USGS OPERATED Kprm OBSERVATION WELLS.

MEAN DAILY WATER LEVELS.

Appendix 6

MODEL INPUT DATA (LAYER 1)#

Node	2,33
T	9.29×10^{-5}
TK	9.29×10^{-11}

#T in m^2/sec   TK in sec^{-1}

Appendix 6

MODEL INPUT DATA (LAYER 1)*

Node	2,33
T	9.29×10^{-5}
TK	9.29×10^{-11}

*T in m^2/sec   TK in sec^{-1}

MODEL INPUT DATA (LAYER 2)*

Node	2	3	4	5	6	7	8	9
T	3.25×10^{-4}	6.5×10^{-3}	5.6×10^{-3}	4.6×10^{-3}	3.7×10^{-3}	3.8×10^{-3}	2.8×10^{-3}	6.5×10^{-3}
TK	9.3×10^{-9}	2.8×10^{-5}	9.3×10^{-7}	9.3×10^{-7}	9.3×10^{-6}	4.6×10^{-5}	4.6×10^{-5}	4.6×10^{-5}
Node	10	11	12	13	14	15	16	17
T	7.4×10^{-3}	8.4×10^{-3}	6.5×10^{-3}	6.5×10^{-3}	2.8×10^{-3}	2.8×10^{-4}	6.5×10^{-4}	9.3×10^{-6}
TK	4.6×10^{-5}	4.6×10^{-5}	9.3×10^{-7}	9.3×10^{-7}	9.3×10^{-7}	9.3×10^{-6}	9.3×10^{-6}	4.6×10^{-5}
Node	18	19	20	21	22	23	24	25
T	4.6×10^{-6}	7.4×10^{-6}	7.6×10^{-6}	9.3×10^{-7}	4.6×10^{-6}	4.6×10^{-6}	4.6×10^{-6}	4.6×10^{-6}
TK	4.6×10^{-5}	4.6×10^{-6}	9.3×10^{-8}	9.3×10^{-8}	9.3×10^{-8}	9.3×10^{-8}	9.3×10^{-8}	9.3×10^{-6}
Node	26	27	28	29	30	31	32	33
T	4.6×10^{-6}	6.5×10^{-6}	6.5×10^{-6}	9.3×10^{-6}	2.8×10^{-5}	4.6×10^{-4}	2.8×10^{-3}	2.8×10^{-4}
TK	4.6×10^{-6}	9.3×10^{-6}	4.6×10^{-5}	4.6×10^{-5}	4.6×10^{-5}	4.6×10^{-5}	4.6×10^{-5}	9.3×10^{-9}

*T in m^2/sec   TK in sec^{-1}

MODEL INPUT DATA (LAYER 2)*

Node	2	3	4	5	6	7	8	9
T	3.25×10^{-4}	6.5×10^{-3}	5.6×10^{-3}	4.6×10^{-3}	3.7×10^{-3}	3.8×10^{-3}	2.8×10^{-3}	6.5×10^{-3}
TK	9.3×10^{-9}	2.8×10^{-5}	9.3×10^{-7}	9.3×10^{-7}	9.3×10^{-6}	4.6×10^{-5}	4.6×10^{-5}	4.6×10^{-5}

Node	10	11	12	13	14	15	16	17
T	7.4×10^{-3}	8.4×10^{-3}	6.5×10^{-3}	6.5×10^{-3}	2.8×10^{-3}	2.8×10^{-4}	6.5×10^{-4}	9.3×10^{-6}
TK	4.6×10^{-5}	4.6×10^{-5}	9.3×10^{-7}	9.3×10^{-7}	9.3×10^{-7}	9.3×10^{-6}	9.3×10^{-6}	4.6×10^{-5}

Node	18	19	20	21	22	23	24	25
T	4.6×10^{-6}	7.4×10^{-6}	7.6×10^{-6}	9.3×10^{-7}	4.6×10^{-6}	4.6×10^{-6}	4.6×10^{-6}	4.6×10^{-6}
TK	4.6×10^{-5}	4.6×10^{-6}	9.3×10^{-8}	9.3×10^{-8}	9.3×10^{-8}	9.3×10^{-8}	9.3×10^{-8}	9.3×10^{-6}

Node	26	27	28	29	30	31	32	33
T	4.6×10^{-6}	6.5×10^{-6}	6.5×10^{-6}	9.3×10^{-6}	2.8×10^{-5}	4.6×10^{-4}	2.8×10^{-3}	2.8×10^{-4}
TK	4.6×10^{-6}	9.3×10^{-6}	4.6×10^{-5}	4.6×10^{-5}	4.6×10^{-5}	4.6×10^{-5}	4.6×10^{-5}	9.3×10^{-9}

*T in m^2/sec TK in sec^{-1}

MODEL INPUT DATA (LAYER 3)*

Node	2	3	4	5	6	7	8	9
T	9.3×10^{-5}	7.4×10^{-5}	9.3×10^{-6}	4.6×10^{-5}	2.8×10^{-3}	2.8×10^{-3}	9.3×10^{-4}	2.8×10^{-3}
TK	9.3×10^{-5}	9.3×10^{-7}	9.3×10^{-8}	4.6×10^{-7}	2.8×10^{-5}	2.8×10^{-5}	2.3×10^{-5}	2.8×10^{-5}
Node	10	11	12	13	14	15	16	17
T	9.3×10^{-4}	9.3×10^{-4}	3.7×10^{-4}	3.7×10^{-4}	3.7×10^{-4}	2.8×10^{-3}	2.8×10^{-4}	2.8×10^{-4}
TK	4.6×10^{-5}	4.6×10^{-5}	4.6×10^{-5}	4.6×10^{-5}	4.6×10^{-5}	4.6×10^{-5}	4.6×10^{-5}	4.6×10^{-5}
Node	18	19	20	21	22	23	24	25
T	2.8×10^{-3}	2.8×10^{-3}	4.6×10^{-5}	4.6×10^{-6}	4.6×10^{-6}	4.6×10^{-6}	4.6×10^{-6}	4.6×10^{-4}
TK	4.6×10^{-5}	9.3×10^{-8}	9.3×10^{-8}	9.3×10^{-8}	9.3×10^{-8}	9.3×10^{-7}	9.3×10^{-7}	9.3×10^{-6}
Node	26	27	28	29	30	31	32	33
T	4.6×10^{-4}	2.8×10^{-3}	2.8×10^{-3}	2.8×10^{-3}	2.8×10^{-3}	2.8×10^{-3}	2.8×10^{-3}	2.8×10^{-4}
TK	2.8×10^{-5}	4.6×10^{-5}	4.6×10^{-5}	4.6×10^{-5}	4.6×10^{-5}	4.6×10^{-6}	4.6×10^{-6}	9.3×10^{-6}

*T in m^2/sec TK in sec^{-1}

MODEL INPUT DATA (LAYER 3)*

Node	2	3	4	5	6	7	8	9
T	$9.3x10^{-5}$	$7.4x10^{-5}$	$9.3x10^{-6}$	$4.6x10^{-5}$	$2.8x10^{-3}$	$2.8x10^{-3}$	$9.3x10^{-4}$	$2.8x10^{-3}$
TK	$9.3x10^{-5}$	$9.3x10^{-7}$	$9.3x10^{-8}$	$4.6x10^{-7}$	$2.8x10^{-5}$	$2.8x10^{-5}$	$2.3x10^{-5}$	$2.8x10^{-5}$
Node	10	11	12	13	14	15	16	17
T	$9.3x10^{-4}$	$9.3x10^{-4}$	$3.7x10^{-4}$	$3.7x10^{-4}$	$3.7x10^{-4}$	$2.8x10^{-3}$	$2.8x10^{-4}$	$2.8x10^{-4}$
TK	$4.6x10^{-5}$	$4.6x10^{-5}$	$4.6x10^{-5}$	$4.6x10^{-5}$	$4.6x10^{-5}$	$4.6x10^{-5}$	$4.6x10^{-5}$	$4.6x10^{-5}$
Node	18	19	20	21	22	23	24	25
T	$2.8x10^{-3}$	$2.8x10^{-3}$	$4.6x10^{-5}$	$4.6x10^{-6}$	$4.6x10^{-6}$	$4.6x10^{-6}$	$4.6x10^{-6}$	$4.6x10^{-4}$
TK	$4.6x10^{-5}$	$9.3x10^{-8}$	$9.3x10^{-8}$	$9.3x10^{-8}$	$9.3x10^{-8}$	$9.3x10^{-7}$	$9.3x10^{-7}$	$9.3x10^{-6}$
Node	26	27	28	29	30	31	32	33
T	$4.6x10^{-4}$	$2.8x10^{-3}$	$2.8x10^{-3}$	$2.8x10^{-3}$	$2.8x10^{-3}$	$2.8x10^{-3}$	$2.8x10^{-3}$	$2.8x10^{-4}$
TK	$2.8x10^{-5}$	$4.6x10^{-5}$	$4.6x10^{-5}$	$4.6x10^{-5}$	$4.6x10^{-5}$	$4.6x10^{-6}$	$4.6x10^{-6}$	$9.3x10^{-6}$

*T in m^2/sec TK in sec^{-1}

MODEL INPUT DATA (LAYER 4)*

Node	2	3	4	5	6	7	8	9
T	2.8×10^{-2}	4.6×10^{-4}	9.3×10^{-5}	4.6×10^{-4}	2.8×10^{-3}	2.8×10^{-3}	2.8×10^{-3}	2.8×10^{-3}
TK	9.3×10^{-8}	4.6×10^{-5}	4.6×10^{-5}	9.3×10^{-7}	4.6×10^{-5}	4.6×10^{-5}	4.6×10^{-5}	4.6×10^{-5}
Node	10	11	12	13	14	15	16	17
T	6.5×10^{-4}	6.5×10^{-4}	6.5×10^{-4}	2.8×10^{-3}	2.8×10^{-3}	2.8×10^{-3}	3.7×10^{-3}	6.5×10^{-4}
TK	4.6×10^{-5}	4.6×10^{-5}	4.6×10^{-7}	4.6×10^{-9}	4.6×10^{-9}	4.6×10^{-9}	4.6×10^{-9}	4.6×10^{-9}
Node	18	19	20	21	22	23	24	25
T	6.5×10^{-4}	6.5×10^{-4}	6.5×10^{-4}	2.8×10^{-3}	2.8×10^{-3}	2.8×10^{-3}	4.6×10^{-4}	6.5×10^{-4}
TK	4.6×10^{-6}	4.6×10^{-6}	4.6×10^{-5}	4.6×10^{-5}	4.6×10^{-5}	4.6×10^{-5}	4.6×10^{-5}	4.6×10^{-5}
Node	26	27	28	29	30	31	32	33
T	6.5×10^{-4}	2.8×10^{-3}	2.8×10^{-3}	2.8×10^{-3}	2.8×10^{-3}	2.8×10^{-3}	2.8×10^{-3}	2.8×10^{-3}
TK	4.6×10^{-5}	4.6×10^{-5}	4.6×10^{-5}	4.6×10^{-5}	4.6×10^{-5}	4.6×10^{-5}	4.6×10^{-5}	9.3×10^{-8}

*T in m^2/sec   TK in sec^{-1}

MODEL INPUT DATA (LAYER 4)*

Node	2	3	4	5	6	7	8	9
T	$2.8x10^{-2}$	$4.6x10^{-4}$	$9.3x10^{-5}$	$4.6x10^{-4}$	$2.8x10^{-3}$	$2.8x10^{-3}$	$2.8x10^{-3}$	$2.8x10^{-3}$
TK	$9.3x10^{-8}$	$4.6x10^{-5}$	$4.6x10^{-5}$	$9.3x10^{-7}$	$4.6x10^{-5}$	$4.6x10^{-5}$	$4.6x10^{-5}$	$4.6x10^{-5}$

Node	10	11	12	13	14	15	16	17
T	$6.5x10^{-4}$	$6.5x10^{-4}$	$6.5x10^{-4}$	$2.8x10^{-3}$	$2.8x10^{-3}$	$2.8x10^{-3}$	$3.7x10^{-3}$	$6.5x10^{-4}$
TK	$4.6x10^{-5}$	$4.6x10^{-5}$	$4.6x10^{-7}$	$4.6x10^{-9}$	$4.6x10^{-9}$	$4.6x10^{-9}$	$4.6x10^{-9}$	$4.6x10^{-9}$

Node	18	19	20	21	22	23	24	25
T	$6.5x10^{-4}$	$6.5x10^{-4}$	$6.5x10^{-4}$	$2.8x10^{-3}$	$2.8x10^{-3}$	$2.8x10^{-3}$	$4.6x10^{-4}$	$6.5x10^{-4}$
TK	$4.6x10^{-6}$	$4.6x10^{-6}$	$4.6x10^{-5}$	$4.6x10^{-5}$	$4.6x10^{-5}$	$4.6x10^{-5}$	$4.6x10^{-5}$	$4.6x10^{-5}$

Node	26	27	28	29	30	31	32	33
T	$6.5x10^{-4}$	$2.8x10^{-3}$	$2.8x10^{-3}$	$2.8x10^{-3}$	$2.8x10^{-3}$	$2.8x10^{-3}$	$2.8x10^{-3}$	$2.8x10^{-3}$
TK	$4.6x10^{-5}$	$4.6x10^{-5}$	$4.6x10^{-5}$	$4.6x10^{-5}$	$4.6x10^{-5}$	$4.6x10^{-5}$	$4.6x10^{-5}$	$9.3x10^{-8}$

*T in m^2/sec TK in sec^{-1}

MODEL INPUT DATA (LAYER 5)*

Node	2	3	4	5	6	7	8	9
T	$9.3x10^{-4}$	$9.3x10^{-4}$	$9.3x10^{-4}$	$9.3x10^{-4}$	$9.3x10^{-4}$	$9.3x10^{-4}$	$4.6x10^{-4}$	$9.3x10^{-4}$
TK	$9.3x10^{-8}$	$4.6x10^{-6}$	$4.6x10^{-6}$	$9.3x10^{-9}$	$9.3x10^{-9}$	$9.3x10^{-9}$	$4.6x10^{-8}$	$4.6x10^{-8}$

Node	10	11	12	13	14	15	16	17
T	$9.3x10^{-4}$	$7.4x10^{-4}$	$9.3x10^{-5}$	$4.6x10^{-6}$	$4.6x10^{-6}$	$9.3x10^{-8}$	$9.3x10^{-8}$	$9.3x10^{-8}$
TK	$4.6x10^{-8}$	$4.6x10^{-8}$	$4.6x10^{-8}$	$4.6x10^{-8}$	$9.3x10^{-9}$	$4.6x10^{-9}$	$4.6x10^{-9}$	$4.6x10^{-9}$

Node	18	19	20	21	22	23	24	25
T	$5.6x10^{-4}$	$5.6x10^{-4}$	$6.5x10^{-4}$	$9.3x10^{-4}$	$9.3x10^{-4}$	$9.3x10^{-4}$	$9.3x10^{-4}$	$9.3x10^{-4}$
TK	$4.6x10^{-6}$	$4.6x10^{-5}$	$4.6x10^{-5}$	$4.6x10^{-5}$	$4.6x10^{-5}$	$4.6x10^{-5}$	$4.6x10^{-5}$	$4.6x10^{-5}$

Node	26	27	28	29	30	31	32	33
T	$9.3x10^{-4}$	$9.3x10^{-4}$	$9.3x10^{-4}$	$9.3x10^{-4}$	$9.3x10^{-4}$	$9.3x10^{-4}$	$6.5x10^{-4}$	$6.5x10^{-4}$
TK	$4.6x10^{-5}$	$4.6x10^{-6}$	$4.6x10^{-5}$	$4.6x10^{-5}$	$4.6x10^{-7}$	$4.6x10^{-7}$	$4.6x10^{-7}$	$4.6x10^{-7}$

*T in m^2/sec · TK in sec^{-1}

MODEL INPUT DATA (LAYER 5)*

Node	2	3	4	5	6	7	8	9
T	9.3×10^{-4}	9.3×10^{-4}	9.3×10^{-4}	9.3×10^{-4}	9.3×10^{-4}	9.3×10^{-4}	4.6×10^{-4}	9.3×10^{-4}
TK	9.3×10^{-8}	4.6×10^{-6}	4.6×10^{-6}	9.3×10^{-9}	9.3×10^{-9}	9.3×10^{-9}	4.6×10^{-8}	4.6×10^{-8}

Node	10	11	12	13	14	15	16	17
T	9.3×10^{-4}	7.4×10^{-4}	9.3×10^{-5}	4.6×10^{-6}	4.6×10^{-6}	9.3×10^{-8}	9.3×10^{-8}	9.3×10^{-8}
TK	4.6×10^{-8}	4.6×10^{-8}	4.6×10^{-8}	4.6×10^{-8}	9.3×10^{-9}	4.6×10^{-9}	4.6×10^{-9}	4.6×10^{-9}

Node	18	19	20	21	22	23	24	25
T	5.6×10^{-4}	5.6×10^{-4}	6.5×10^{-4}	9.3×10^{-4}	9.3×10^{-4}	9.3×10^{-4}	9.3×10^{-4}	9.3×10^{-4}
TK	4.6×10^{-6}	4.6×10^{-5}	4.6×10^{-5}	4.6×10^{-5}	4.6×10^{-5}	4.6×10^{-5}	4.6×10^{-5}	4.6×10^{-5}

Node	26	27	28	29	30	31	32	33
T	9.3×10^{-4}	9.3×10^{-4}	9.3×10^{-4}	9.3×10^{-4}	9.3×10^{-4}	9.3×10^{-4}	6.5×10^{-4}	6.5×10^{-4}
TK	4.6×10^{-5}	4.6×10^{-6}	4.6×10^{-5}	4.6×10^{-5}	4.6×10^{-7}	4.6×10^{-7}	4.6×10^{-7}	4.6×10^{-7}

*T in m^2/sec TK in sec^{-1}

MODEL INPUT DATA (LAYER 6)*

Node	2	3	4	5	6	7	8	9
T	4.6×10^{-4}	4.6×10^{-4}	4.6×10^{-7}	4.6×10^{-6}	4.6×10^{-7}	4.6×10^{-7}	4.6×10^{-7}	4.6×10^{-7}
TK	9.3×10^{-9}	4.6×10^{-5}	4.6×10^{-6}	4.6×10^{-7}	4.6×10^{-7}	4.6×10^{-7}	4.6×10^{-8}	4.6×10^{-8}

Node	10	11	12	13	14	15	16	17
T	4.6×10^{-7}	9.3×10^{-7}	9.3×10^{-5}	6.5×10^{-4}	6.5×10^{-4}	4.6×10^{-6}	9.3×10^{-8}	9.3×10^{-8}
TK	4.6×10^{-7}	4.6×10^{-7}	4.6×10^{-6}	4.6×10^{-8}	9.3×10^{-8}	9.3×10^{-8}	4.6×10^{-8}	4.6×10^{-7}

Node	18	19	20	21	22	23	24	25
T	5.6×10^{-4}	6.5×10^{-4}	6.5×10^{-4}	9.3×10^{-4}	9.3×10^{-5}	6.5×10^{-4}	4.6×10^{-4}	4.6×10^{-4}
TK	4.6×10^{-5}	4.6×10^{-4}	4.6×10^{-5}	9.3×10^{-9}	4.6×10^{-5}	4.6×10^{-5}	4.6×10^{-5}	4.6×10^{-5}

Node	26	27	28	29	30	31	32	33
T	6.5×10^{-4}	6.5×10^{-4}	6.5×10^{-4}	6.5×10^{-4}	6.5×10^{-4}	6.5×10^{-4}	6.5×10^{-4}	6.5×10^{-4}
TK	4.6×10^{-8}	4.6×10^{-8}	4.6×10^{-5}	4.6×10^{-5}	4.6×10^{-5}	4.6×10^{-5}	4.6×10^{-5}	9.3×10^{-9}

*T in m^2/sec TK in sec^{-1}

MODEL INPUT DATA (LAYER 6)*

Node	2	3	4	5	6	7	8	9
T	4.6×10^{-4}	4.6×10^{-4}	4.6×10^{-7}	4.6×10^{-6}	4.6×10^{-7}	4.6×10^{-7}	4.6×10^{-7}	4.6×10^{-7}
TK	9.3×10^{-9}	4.6×10^{-5}	4.6×10^{-6}	4.6×10^{-7}	4.6×10^{-7}	4.6×10^{-7}	4.6×10^{-8}	4.6×10^{-8}

Node	10	11	12	13	14	15	16	17
T	4.6×10^{-7}	9.3×10^{-7}	9.3×10^{-5}	6.5×10^{-4}	6.5×10^{-4}	4.6×10^{-6}	9.3×10^{-8}	9.3×10^{-8}
TK	4.6×10^{-7}	4.6×10^{-7}	4.6×10^{-6}	4.6×10^{-8}	9.3×10^{-8}	9.3×10^{-8}	4.6×10^{-8}	4.6×10^{-7}

Node	18	19	20	21	22	23	24	25
T	5.6×10^{-4}	6.5×10^{-4}	6.5×10^{-4}	9.3×10^{-4}	9.3×10^{-5}	6.5×10^{-4}	4.6×10^{-4}	4.6×10^{-4}
TK	4.6×10^{-5}	4.6×10^{-4}	4.6×10^{-5}	9.3×10^{-9}	4.6×10^{-5}	4.6×10^{-5}	4.6×10^{-5}	4.6×10^{-5}

Node	26	27	28	29	30	31	32	33
T	6.5×10^{-4}	6.5×10^{-4}	6.5×10^{-4}	6.5×10^{-4}	6.5×10^{-4}	6.5×10^{-4}	6.5×10^{-4}	6.5×10^{-4}
TK	4.6×10^{-8}	4.6×10^{-8}	4.6×10^{-5}	4.6×10^{-5}	4.6×10^{-5}	4.6×10^{-5}	4.6×10^{-5}	9.3×10^{-9}

*T in m^2/sec TK in sec^{-1}

MODEL INPUT DATA (LAYER 7)*

Node	2	3	4	5	6	7	8	9
T	4.6×10^{-5}	4.6×10^{-4}	4.6×10^{-6}	9.3×10^{-5}	4.6×10^{-7}	9.3×10^{-7}	4.6×10^{-7}	3.7×10^{-5}
TK	9.3×10^{-9}	4.6×10^{-6}	4.6×10^{-6}	4.6×10^{-8}	4.6×10^{-4}	4.6×10^{-5}	4.6×10^{-4}	4.6×10^{-8}
Node	10	11	12	13	14	15	16	17
T	4.6×10^{-7}	3.7×10^{-5}	9.3×10^{-8}	9.3×10^{-6}	9.3×10^{-6}	4.6×10^{-6}	7.4×10^{-6}	6.5×10^{-4}
TK	9.3×10^{-5}	4.6×10^{-7}	4.6×10^{-6}	4.6×10^{-8}	4.6×10^{-6}	4.6×10^{-5}	4.6×10^{-6}	4.6×10^{-5}
Node	18	19	20	21	22	23	24	25
T	6.5×10^{-4}	6.5×10^{-4}	6.5×10^{-4}	6.5×10^{-4}	6.5×10^{-4}	6.5×10^{-4}	6.5×10^{-4}	6.5×10^{-4}
TK	4.6×10^{-5}	9.3×10^{-6}	9.3×10^{-6}	4.6×10^{-8}	9.3×10^{-6}	9.3×10^{-6}	4.6×10^{-5}	4.6×10^{-5}
Node	26	27	28	29	30	31	32	33
T	6.5×10^{-4}	9.3×10^{-6}	6.5×10^{-4}	6.5×10^{-4}	6.5×10^{-4}	6.5×10^{-4}	6.5×10^{-4}	6.5×10^{-4}
TK	4.6×10^{-5}	4.6×10^{-8}	4.6×10^{-8}	4.6×10^{-5}	4.6×10^{-5}	4.6×10^{-5}	4.6×10^{-5}	9.3×10^{-9}

*T in m^2/sec TK in sec^{-1}

MODEL INPUT DATA (LAYER 7)*

Node	2	3	4	5	6	7	8	9
T	4.6×10^{-5}	4.6×10^{-4}	4.6×10^{-6}	9.3×10^{-5}	4.6×10^{-7}	9.3×10^{-7}	4.6×10^{-7}	3.7×10^{-5}
TK	9.3×10^{-9}	4.6×10^{-6}	4.6×10^{-6}	4.6×10^{-8}	4.6×10^{-4}	4.6×10^{-5}	4.6×10^{-4}	4.6×10^{-8}

Node	10	11	12	13	14	15	16	17
T	4.6×10^{-7}	3.7×10^{-5}	9.3×10^{-8}	9.3×10^{-6}	9.3×10^{-6}	4.6×10^{-6}	7.4×10^{-6}	6.5×10^{-4}
TK	9.3×10^{-5}	4.6×10^{-7}	4.6×10^{-6}	4.6×10^{-8}	4.6×10^{-6}	4.6×10^{-5}	4.6×10^{-6}	4.6×10^{-5}

Node	18	19	20	21	22	23	24	25
T	6.5×10^{-4}	6.5×10^{-4}	6.5×10^{-4}	6.5×10^{-4}	6.5×10^{-4}	6.5×10^{-4}	6.5×10^{-4}	6.5×10^{-4}
TK	4.6×10^{-5}	9.3×10^{-6}	9.3×10^{-6}	4.6×10^{-8}	9.3×10^{-6}	9.3×10^{-6}	4.6×10^{-5}	4.6×10^{-5}

Node	26	27	28	29	30	31	32	33
T	6.5×10^{-4}	9.3×10^{-6}	6.5×10^{-4}	6.5×10^{-4}	6.5×10^{-4}	6.5×10^{-4}	6.5×10^{-4}	6.5×10^{-4}
TK	4.6×10^{-5}	4.6×10^{-8}	4.6×10^{-8}	4.6×10^{-5}	4.6×10^{-5}	4.6×10^{-5}	4.6×10^{-5}	9.3×10^{-9}

*T in m^2/sec TK in sec^{-1}

MODEL INPUT DATA (LAYER 8)*

Node	1	2	3	4	5	6	7	8
K		3.2×10^{-5}	3.2×10^{-3}	3.2×10^{-3}	3.2×10^{-5}	1.4×10^{-3}	3.2×10^{-3}	3.2×10^{-3}
$\hat{y}$	548	548	488	610	488	427	427	427
Node	9	10	11	12	13	14	15	16
K	3.2×10^{-4}	2.3×10^{-4}	2.3×10^{-4}	2.3×10^{-4}	2.3×10^{-3}	2.3×10^{-3}	2.3×10^{-3}	2.3×10^{-3}
$\hat{y}$	305	244	305	305	366	366	305	305
Node	17	18	19	20	21	22	23	24
K	2.3×10^{-3}	2.3×10^{-3}	2.3×10^{-3}	2.3×10^{-3}	1.4×10^{-5}	2.3×10^{-3}	2.3×10^{-3}	2.3×10^{-3}
$\hat{y}$	244	183	183	183	183	183	183	122
Node	25	26	27	28	29	30	31	32
K	2.3×10^{-3}	2.3×10^{-3}	4.6×10^{-6}	4.6×10^{-4}	2.3×10^{-3}	2.3×10^{-3}	2.3×10^{-3}	2.3×10^{-3}
$\hat{y}$	183	183	183	274	305	305	305	305
Node	33							
K	2.3×10^{-5}							
$\hat{y}$	244							

*K in m/sec $\hat{y}$ in m

MODEL INPUT DATA (LAYER 8)*

Node	1	2	3	4	5	6	7	8
K		3.2×10^{-5}	3.2×10^{-3}	3.2×10^{-3}	3.2×10^{-5}	1.4×10^{-3}	3.2×10^{-3}	3.2×10^{-3}
Δy	548	548	488	610	488	427	427	427
Node	9	10	11	12	13	14	15	16
K	3.2×10^{-4}	2.3×10^{-4}	2.3×10^{-4}	2.3×10^{-4}	2.3×10^{-3}	2.3×10^{-3}	2.3×10^{-3}	2.3×10^{-3}
Δy	305	244	305	305	366	366	305	305
Node	17	18	19	20	21	22	23	24
K	2.3×10^{-3}	2.3×10^{-3}	2.3×10^{-3}	2.3×10^{-3}	1.4×10^{-5}	2.3×10^{-3}	2.3×10^{-3}	2.3×10^{-3}
Δy	244	183	183	183	183	183	183	122
Node	25	26	27	28	29	30	31	32
K	2.3×10^{-3}	2.3×10^{-3}	4.6×10^{-6}	4.6×10^{-4}	2.3×10^{-3}	2.3×10^{-3}	2.3×10^{-3}	2.3×10^{-3}
Δy	183	183	183	274	305	305	305	305
Node	33							
K	2.3×10^{-5}							
Δy	244							

*K in m/sec Δy in m

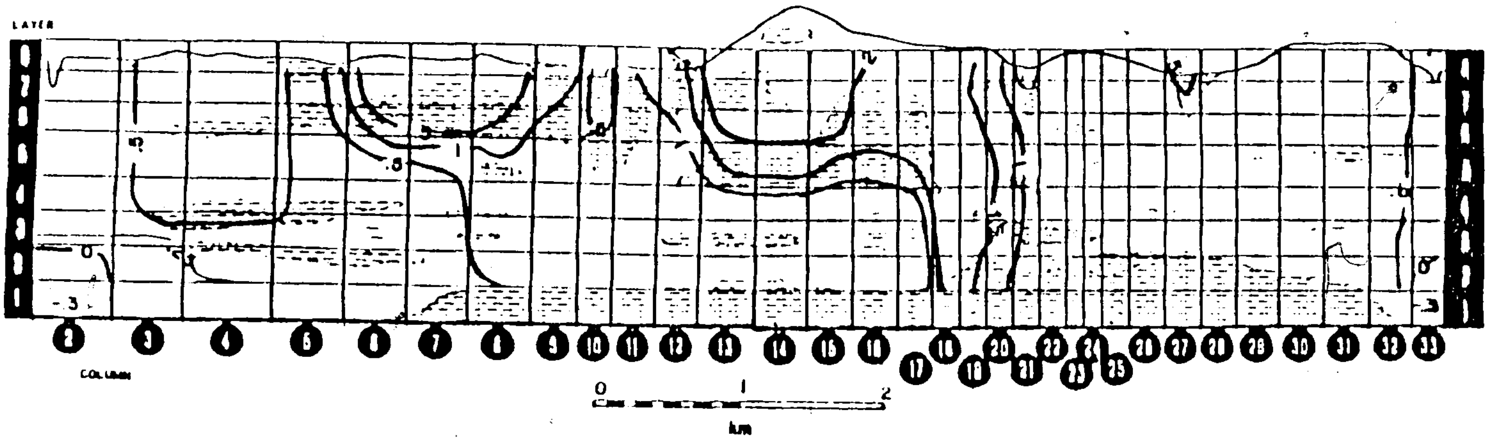


FIGURE A6.1.RESULTS OF 8-LAYER STEADY STATE SIMULATION. RECHARGE=1.52x10^{-8} m/s, TK1=9.3x10^{-1} s^{-1}

EL. OF SURFACE CHNs=.46m

EL. OF BOTTOM CHNs=-.3m

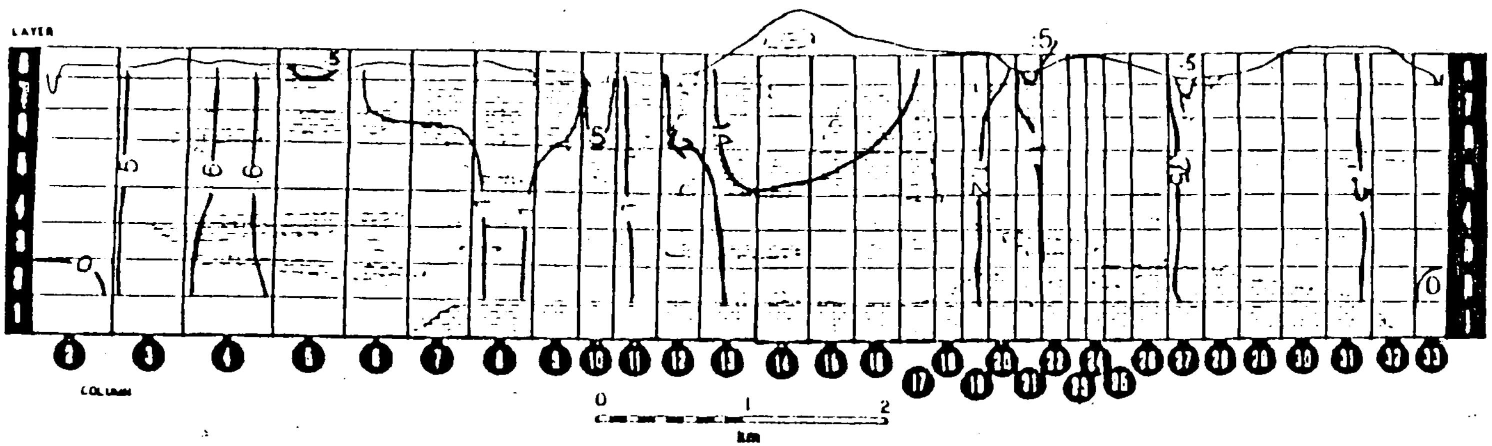


FIGURE A6.2RESULTS OF STEADY STATE SIMULATION. RECHARGE=3.05x10^{-9} m/s

7 LAYERS.

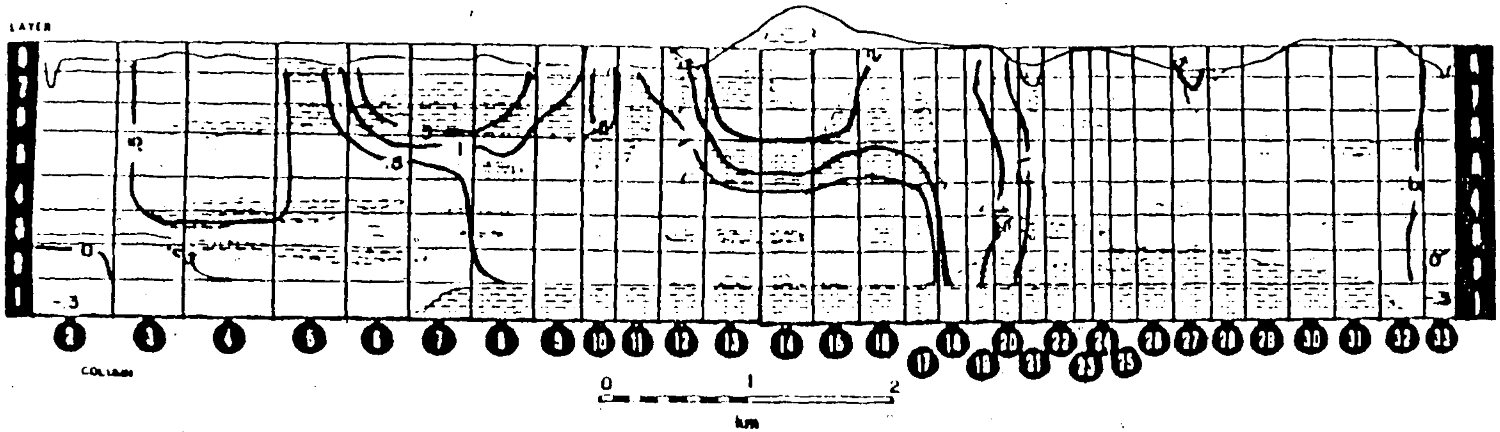


FIGURE A6.1.RESULTS OF 8-LAYER STEADY STATE SIMULATION. RECHARGE=1.52x10^{-8} m/s, TK1=9.3x10^{-1} s^{-1}

EL. OF SURFACE CHNs=.46m

EL. OF BOTTOM CHNs=-.3m

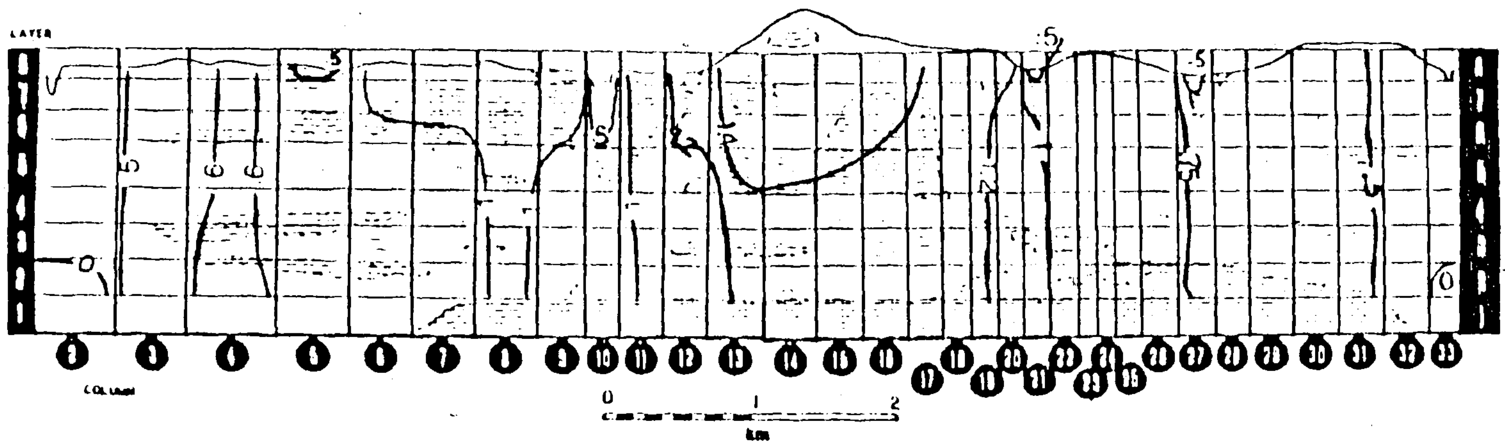


FIGURE A6.2RESULTS OF STEADY STATE SIMULATION. RECHARGE=3.05x10^{-9} m/s

7 LAYERS.

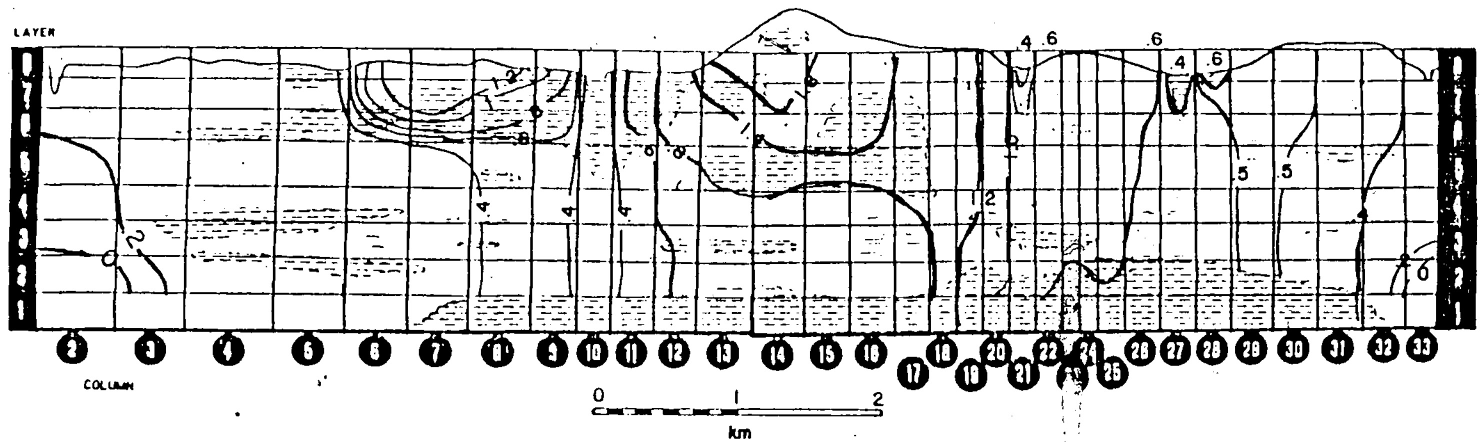


FIGURE A6.3 RESULTS OF 8 LAYER, STEADY STATE SIMULATION. RECHARGE=1.52×10^{-8}, TK=9.31×10^{-10}

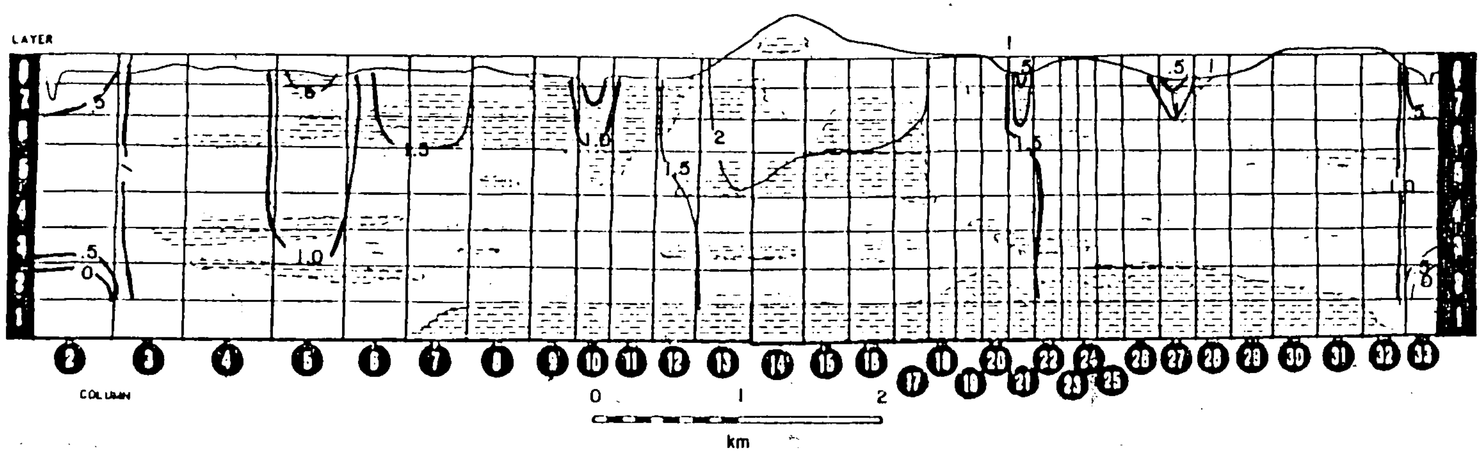
EL. OF SURFACE CHNs=.23m

EL. OF BOTTOM CHNs=-.6M

FIGURE A6.4 RESULTS OF 8LAYER, STEADY STATE SIMULATION. RECHARGE=7.81×10^{-9}, TK1=9.3×10^{-11}

EL. OF SURFACE CHNs=.46m

EL. OF BOTTOM CHNs=-.6m



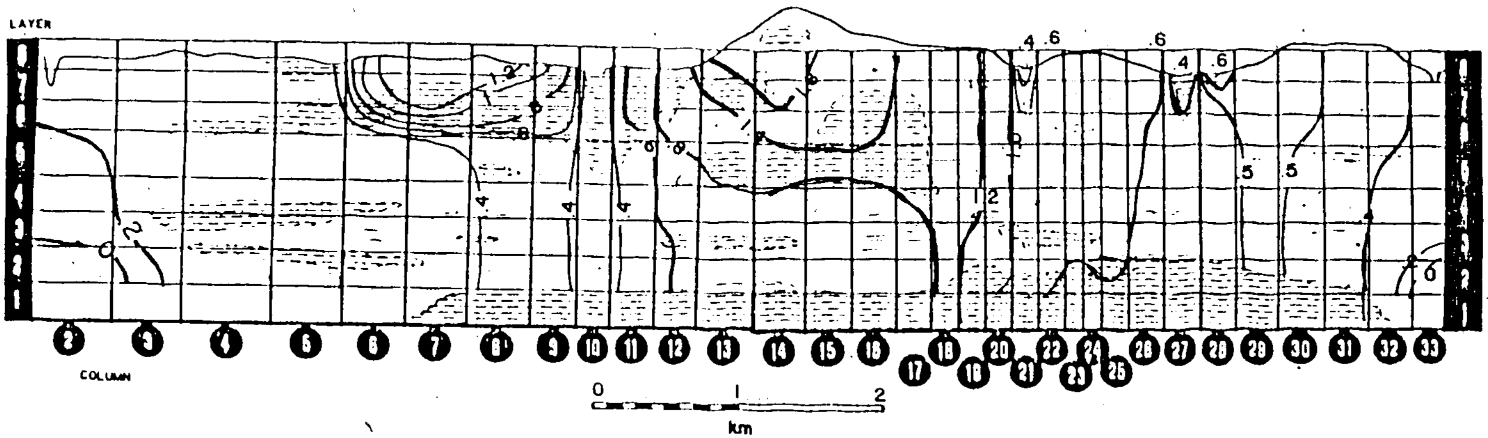


FIGURE A6.3 RESULTS OF 8 LAYER, STEADY STATE SIMULATION. RECHARGE=1.52×10^{-8}, TK=9.31×10^{-10}

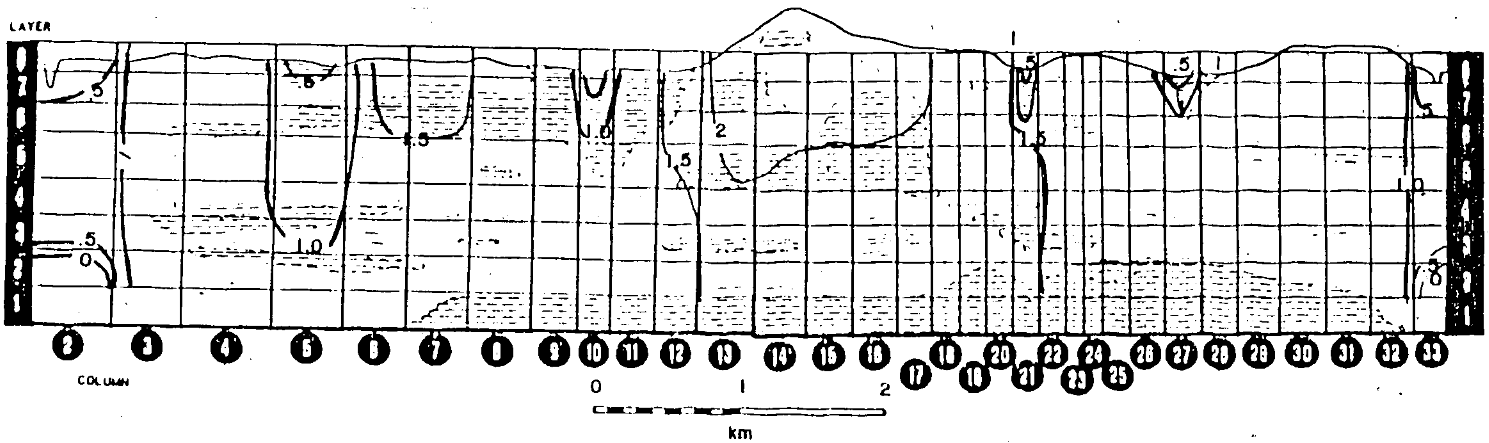
EL. OF SURFACE CHNs=.23m

EL. OF BOTTOM CHNs=-.6M

FIGURE A6.4 RESULTS OF 8LAYER, STEADY STATE SIMULATION. RECHARGE=7.51×10^{-9}, TK1=9.3×10^{-11}

EL. OF SURFACE CHNs=.46m

EL. OF BOTTOM CHNs=.6m



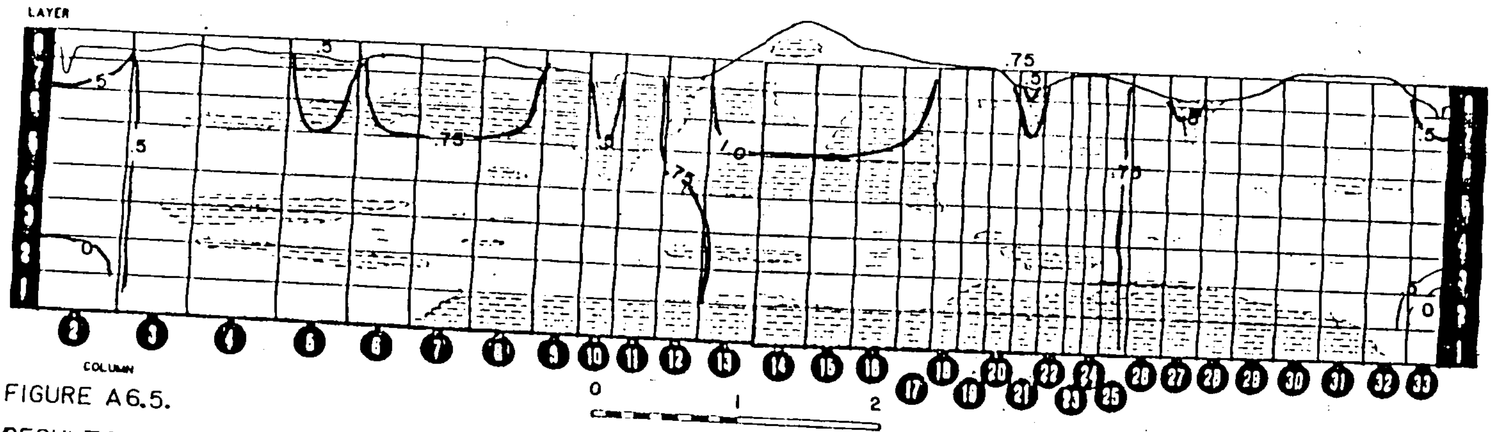


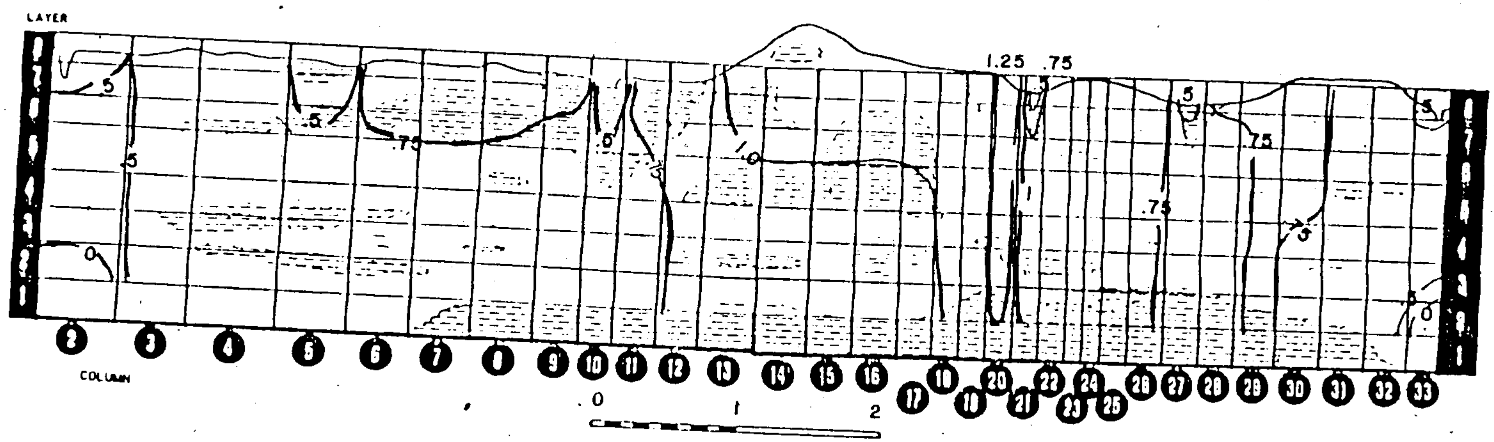
FIGURE A6.5.

RESULTS OF 8 LAYER STEADY STATE SIMULATION USED AS BASE FOR TRANSIENT SIMULATION.

EL. OF SURFACE CHNs=.46m RECHARGE=3.05×10^{-9}, TK1=9.3×10^{-10}

EL. OF BOTTOM CHNs=-.3m

RESULTS OF TRANSIENT SIMULATION RECHARGE=3.05×10^{-8}, 7DAYS



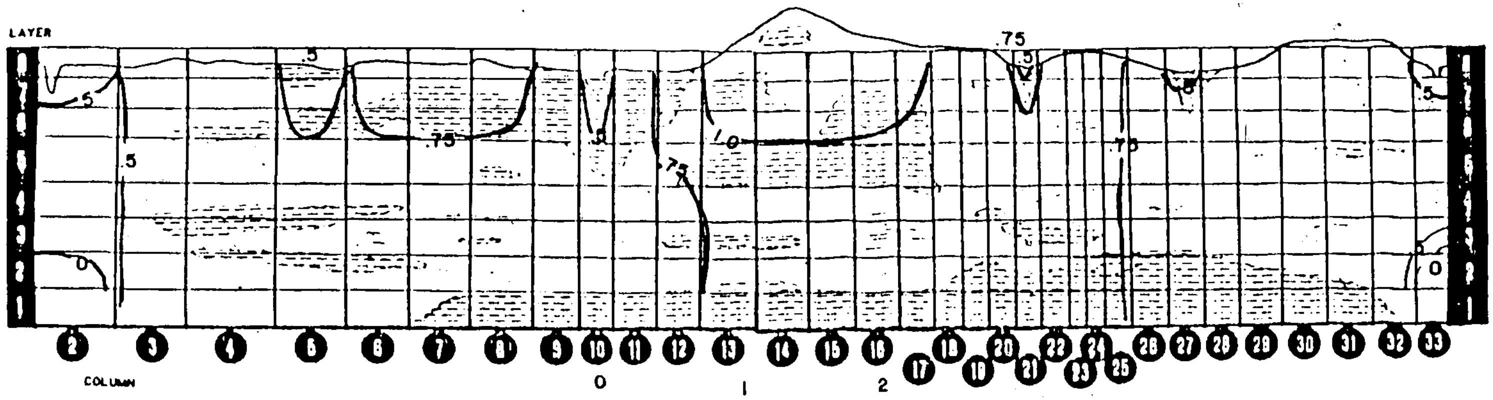


FIGURE A6.5.

RESULTS OF 8 LAYER STEADY STATE SIMULATION USED AS BASE FOR TRANSIENT SIMULATION.

EL. OF SURFACE CHNs=.46m RECHARGE=3.05×10^{-9}, TK1=9.3×10^{-10}

EL. OF BOTTOM CHNs=-.3m

RESULTS OF TRANSIENT SIMULATION RECHARGE=3.05×10^{-8}, 7DAYS

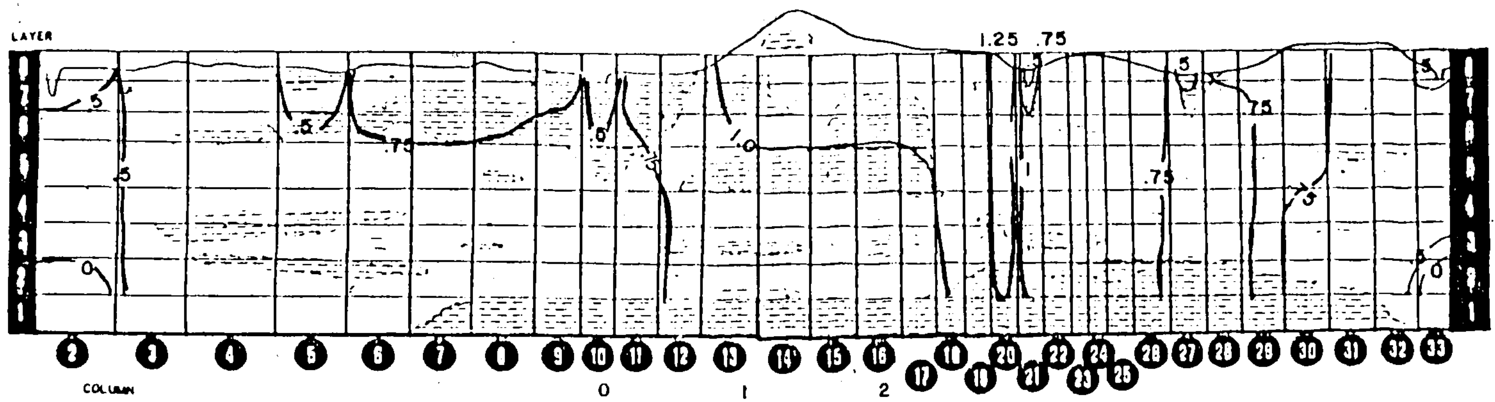


Plate 1. Location Map

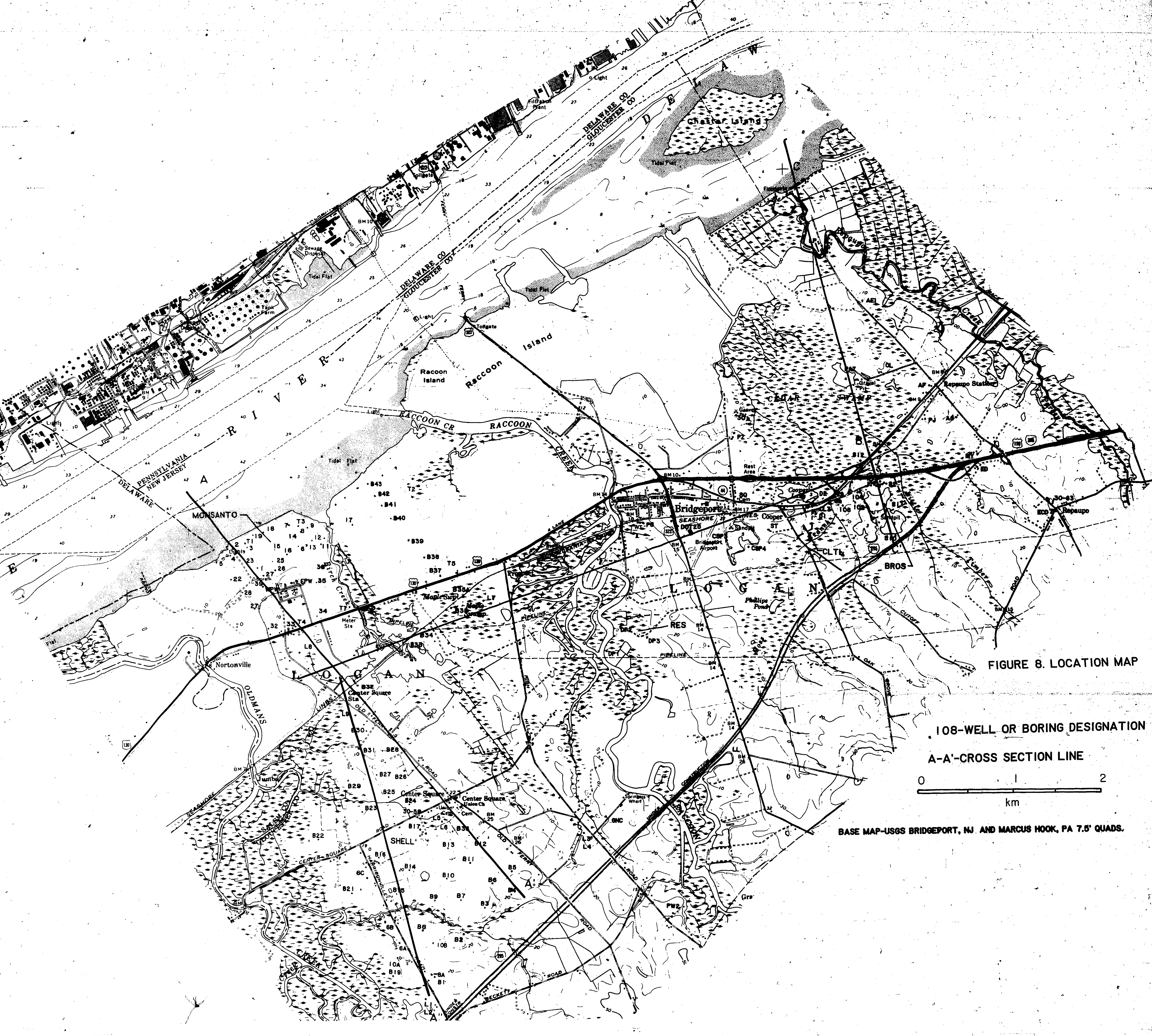


FIGURE 8. LOCATION MAP

Vita

Alan S. Andres, the son of Chester J. Andres Jr. and Dorothy L. Andres, was born on September 5, 1958 at Binghamton, New York. He received a B.S. in Environmental Sciences and Resource Management/Geology from Lehigh University in 1980. Prior to returning to Lehigh for graduate studies, A. 'Scott' Andres was employed by the New Jersey Geological Survey as a geologist in the ground-water pollution analysis unit, for the period July 1980 to August 1982, and again in the summer of 1983. During this period of time he obtained the recieved the motivation and information necessary for the completion of this study.